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Naval Stations Mobile, Pascagoula, and Ingleside as Hurricane Havens

(Change 5 to Hurricane Havens Handbook for the North Atlantic Ocean)

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This publication -- Change 5 to NAVENVPREDRSCHFAC TR 82-03, Hurricane Havens Handbook for the North Atlantic Ocean -- adds port studies of the naval stations at Mobile AL, Pascagoula MS, and Ingleside TX to the basic volume and its four previously published changes. The complete volume now assesses a total of 25 Atlantic and Gulf Coast U.S. ports as potential safe havens for vessels facing hurricane threats. The handbook is a ready-reference decision-making aid for commanding officers and other personnel responsible for the safety of their ships in such threats. Guidance on threat assessment and choice of appropriate countermeasures is provided for each of the ports.

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CONTENTS*

*May be renumbered p. vi and added to basic volume containing changes 1-4.

FOREWORD TO CHANGE 5*

OF

HURRICANE HAVENS HANDBOOK FOR THE NORTH ATLANTIC OCEAN

This publication adds three more sections to the basic volume: port studies of Naval Stations Mobile AL, Pascagoula MS, and Ingleside TX. Recipients who do not hold the basic volume or previously distributed changes 1,2,3,4 may request these publications by letter to Naval Research Laboratory, attention D. Perryman, 7 Grace Hopper Avenue stop 2, Monterey, CA 93943-5502.

The basic volume was published in June 1982 as TR 82-03 by the Naval Environmental Prediction Research Facility, Monterey, now NRL Marine Meteorology Division. It contained nine port studies and a general guidance section (Defense Technical Information Center accession no. ADA 116101).

Change 1, May 1983, added six port studies (DTIC ADA 130264). Change 2, June 1984, added seven port studies (DTIC ADA 144437). Change 3, June 1987, revised and updated the Norfolk VA port study, Sec. II, provided in the original basic volume (DTIC ADA 183126). Change 4, March 1989, revised and updated portions of the Norfolk study dealing with hurricane anchorage locations (DTIC ADA 268233).

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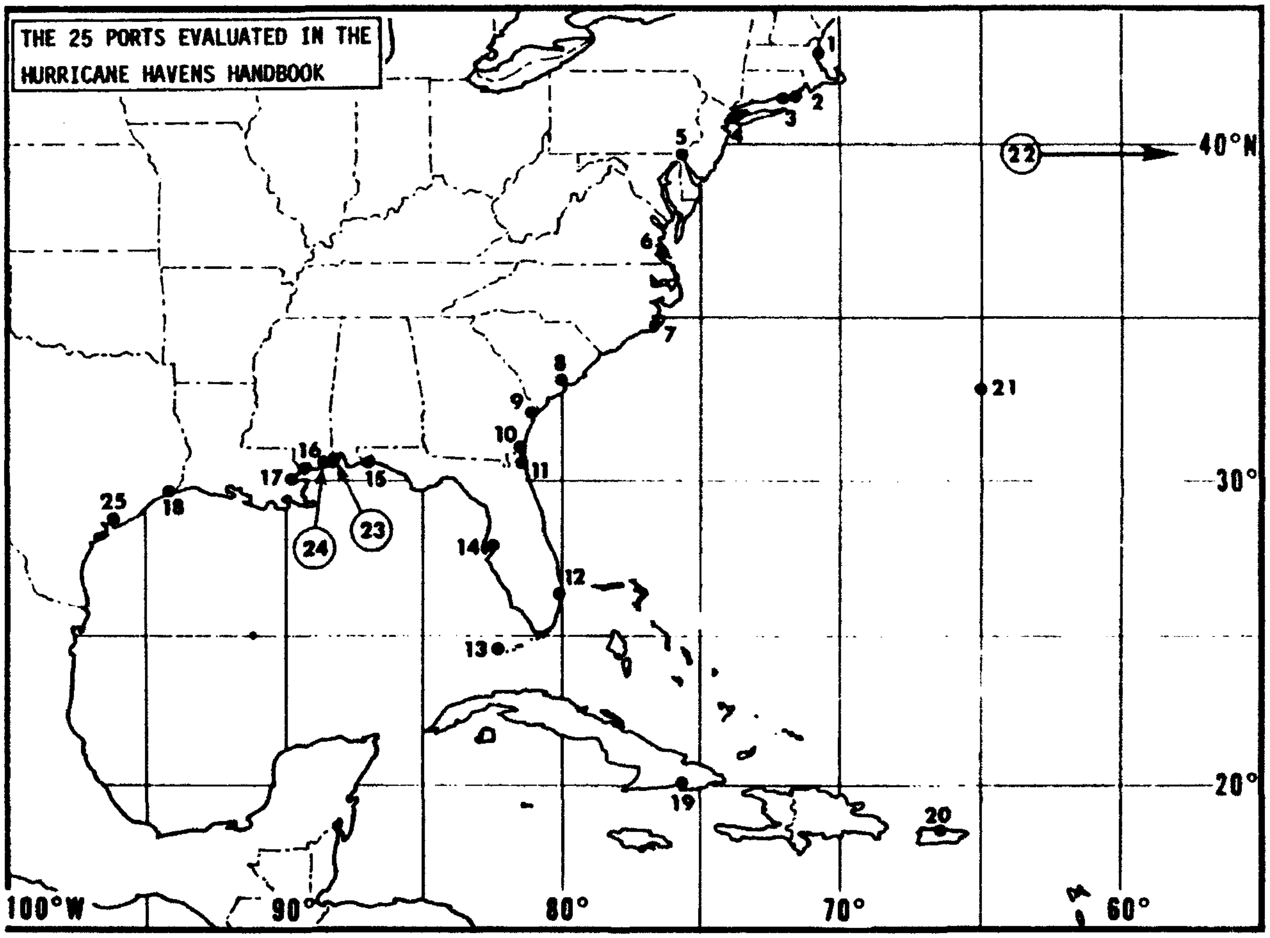
*May be renumbered p. vii-a and added to basic volume containing changes 1-4.

INTRODUCTION

CAUTION: None of the deepwater harbors evaluated in this Handbook have the exceptional qualities needed to safeguard ocean-going vessels from damage in a worst-case direct hurricane strike.

This Handbook provides guidance for assessing a hurricane threat's circumstances and likely impact on the given port to support decision-makers' reasonable choice between either remaining in port or evading at sea. This choice is based on informed compromise between a harbor's protective qualities, and the possibility that a sortie will prove to have been unnecessary.

The general guidance provided in Section I of this Handbook will be of value not only to vessels located at evaluated ports, but also to decision-makers aboard vessels threatened by hurricanes at non-evaluated ports or in transit in the North Atlantic Ocean and Gulf of Mexico.



1 - BOSTON MA	8 - CHARLESTON SC	15 - PENSACOLA FL	22 - PONTA DELGADA AZORES 39N 22W
2 - NEWPORT RI	9 - SAVANNAH GA	16 - GULFPORT MS	23 - MOBILE AL
3 - NEW LONDON CT	10 - KINGS BAY GA	17 - NEW ORLEANS LA	24 - PASCAGOULA MS
4 - NEW YORK NY	11 - MAYPORT FL	18 - PORT ARTHUR TX	25 - INGLESIDE TX
5 - PHILADELPHIA PA	12 - PORT EVERGLADES FL	19 - GUANTANAMO BAY CUBA	
6 - NORFOLK VA	13 - KEY WEST FL	20 - ROOSEVELT ROADS PR	
7 - MOREHEAD CITY NC	14 - TAMPA FL	21 - BERMUDA	

Renumber this sheet front/back as pp ix/x and replace existing sheet in basic volume containing changes 1-4.

RECORD OF CHANGES

CHANGE NO.	DATE OF CHANGE	TYPE OF CHANGE	PAGE NUMBER	DATE ENTERED	ENTERED BY	COMMENTS

XXIV. NS MOBILE, ALABAMA

SUMMARY

The hurricane season poses a serious threat to Naval Station Mobile. During the 107-year period from 1886-1992, an average of one tropical cyclone or hurricane has passed within 180 nmi of Mobile each year. Several storms of record have produced sustained winds in excess of 40 kt with gusts commonly exceeding 60 kt. Dauphin Island reported gusts to 126 kt during Hurricane Frederic in 1979. The area is susceptible to storm surge, with water elevations over 7 ft above mean sea level being recorded at least three times during the period of 1806-1969. Hurricane Frederic generated a 12 ft storm surge in 1979.

The hurricane season for Mobile is from late May through early November, with September being the major threat month. The principal threat is from tropical cyclones approaching from the southwest, south and southeast. When storms of record were at their closest point of approach (CPA) to Mobile, their average monthly direction of movement varied from 339° to 027°, with the overall average direction of movement being 006°.

Mobile is not a hurricane haven. Early threat assessment is essential; limited evasion options dictate that any sortie be initiated soon after Hurricane Condition III is set. Evasion rationale is based on: the susceptibility of the Mobile Bay area to storm surge that could inundate the Naval Station, the absence of sheltered anchorages, the aspect of narrow channels cut through shallow bay waters that would be vulnerable to blockage if a ship should sink during a storm, and the always present danger of damage from other vessels that may break loose from their moorings in the Port of Mobile and other locations on Mobile Bay during strong winds.

Advice for shallow draft vessels is to remove them from the water and transport them to higher ground away from the Naval Station. If that is not feasible, limited shelter may be available in the Mobile River above Mobile.

This hurricane evaluation was prepared by D. Perryman, NRL Monterey CA and R. Gilmore and R. Englebretson, SAIC, Monterey CA.

1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

Naval Station Mobile is located on the western side of Mobile Bay at approximately 30°31'N 88°06'W, in the northeast portion of the Gulf of Mexico (Figure XXIV-1). Mobile Bay is

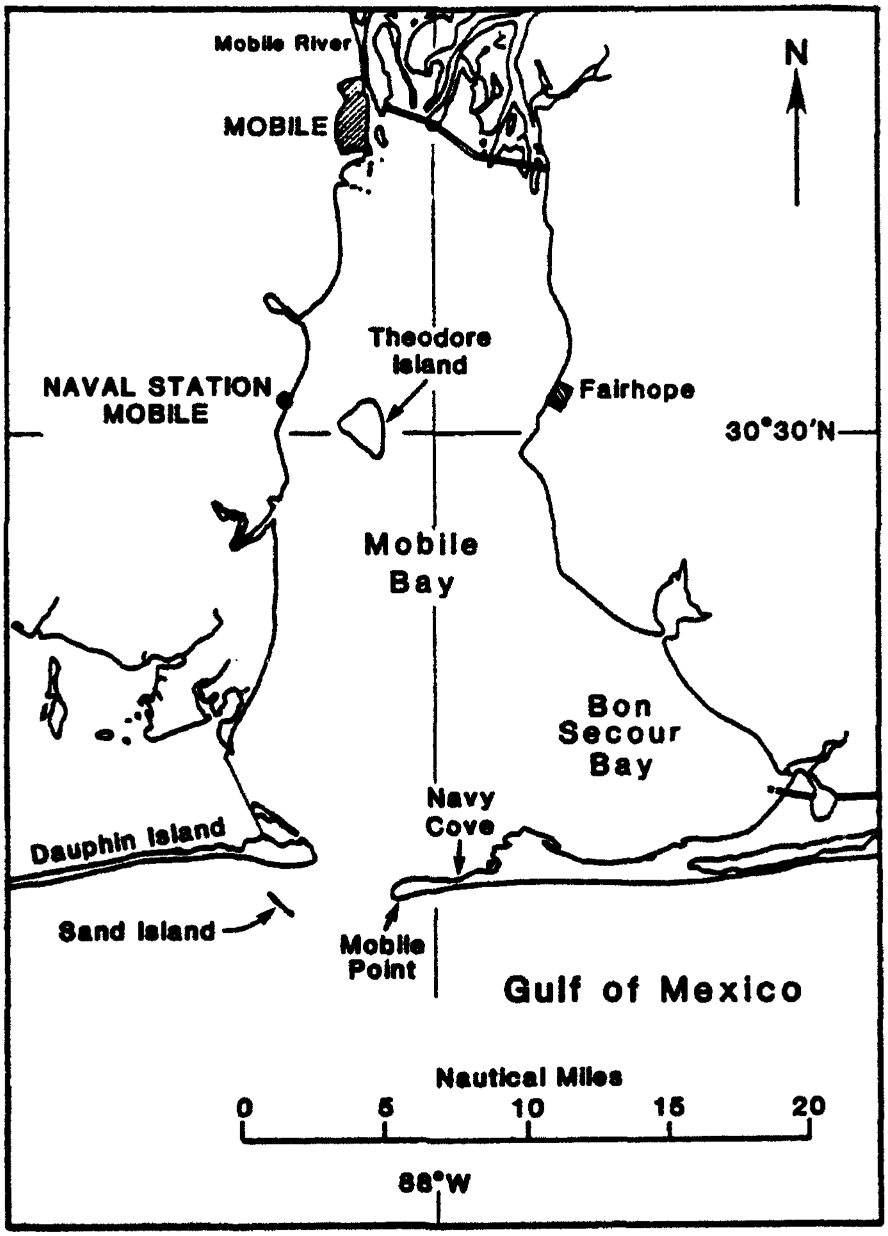


Figure XXIV-1. Location of Mobile, Alabama and Naval Station Mobile on Mobile Bay.

relatively large, extending about 25 nmi from north to south, with a nominal width of about 10 nmi. The 3 nmi wide entrance to the bay is located between Mobile Point on the east, and Sand Island and Dauphin Island on the west. Naval Station Mobile is about 17 nmi north of the bay's entrance.

The Main Ship Channel of Mobile Bay is entered at a point about 5 nmi south of the bay entrance. It extends most of the length of Mobile Bay with a branch, Theodore Ship Channel, extending northwest just south of Theodore Island to the Naval Station (Figure XXIV-2). Project depth for both channels is 40 ft. A third channel, Hollingers Island Channel, extends west from the Main Ship Channel just north of Theodore Island to the area of the Naval Station. Controlling depth of Hollingers Island Channel is only 6 1/2 feet, so it is essentially unusable as a channel by U. S. Navy vessels.

Outside the channels, the bay is relatively shallow, with depths generally ranging from 7 to 11 feet over most of its extent. Terrain elevations surrounding Mobile Bay are low, and the Naval Station is constructed on land which is only 2 to 3 ft above sea level.

Tides are mostly diurnal and the range is only about 1.2 ft at Mobile Point and 1.5 ft in the northern part of the bay. However, strong northerly winds may lower the water level in the bay as much as 1.5 ft below mean low water (U. S. Coast Pilot (1980) as water is forced out of the bay by the frictional effect of the wind on the water. Similarly, hurricanes may raise the water level significantly, caused by a phenomenon known as storm surge which is discussed below in Section 3.3.2. Currents within Mobile Bay are affected considerably by the wind regime.

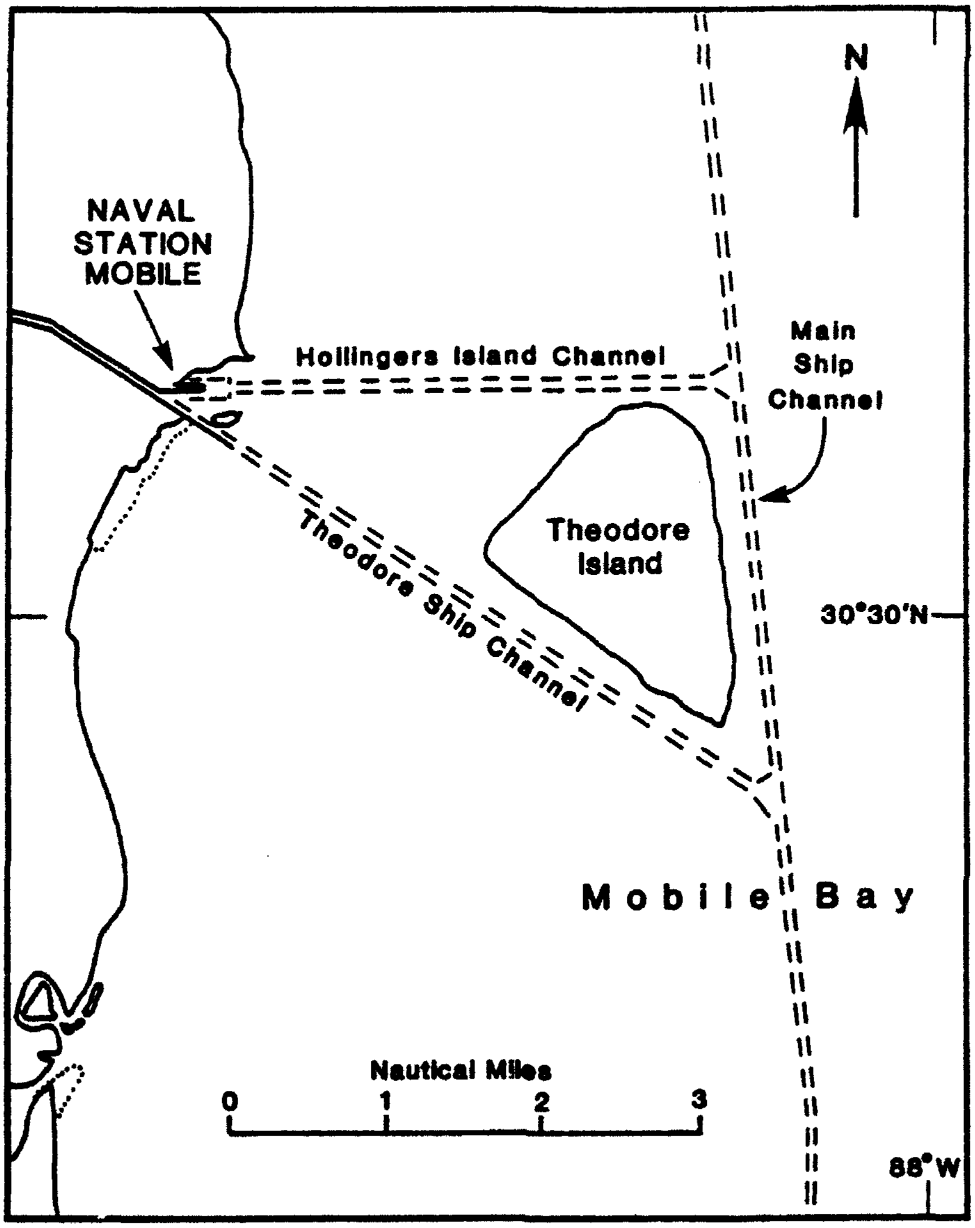


Figure XXIV-2. Location of Naval Station Mobile in relation to Theodore Island and Mobile Bay's ship channels.

2. PORT AND HARBOR FACILITIES

2.1 BERTHING FACILITIES FOR DEEP DRAFT VESSELS

The single pier at the Naval Station is 680 feet long, 80 feet wide, and 18 feet high. See Figure XXIV-3. The four frigates which will be home ported at Mobile will be nested when more than two are in port at the same time. The pier, built in 1991 with two levels, is new in design. All ship services are available from the lower deck. Full services are available on the north quay wall, but none are available on the south side. Additional moorage space for smaller vessels is provided at the quays along the shore at the west end of the pier.

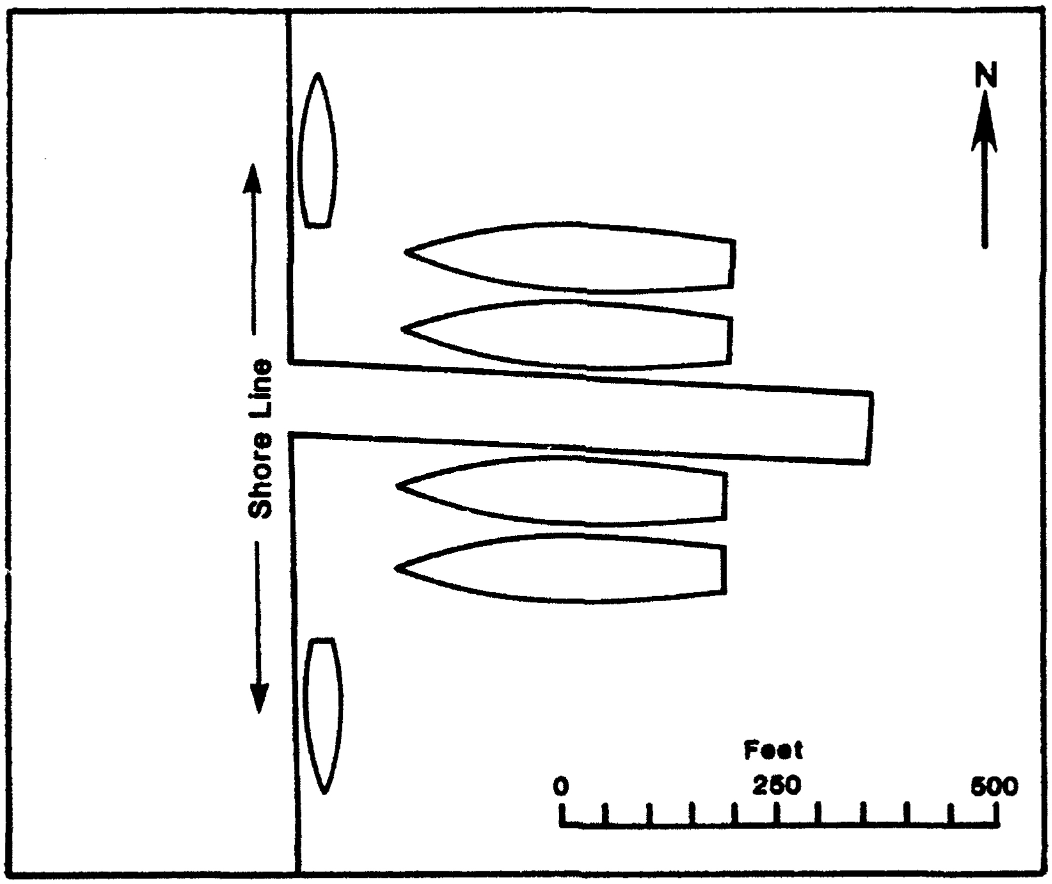


Figure XXIV-3. Configuration of berthing facilities at Naval Station Mobile.

The best anchorages for deep draft vessels in the lower bay are found north and northwest of Mobile Point in depths of 20 to 45 ft (U. S. Department of Commerce, 1980). Holding ground is excellent. It is considered to be a secure anchorage, but strong northerly winds can raise a short choppy sea which may be uncomfortable for small boats. Small boats sometimes anchor at Navy Cove, which is approximately 2 1/2 nmi east of Mobile Point on the north side of the barrier island which defines the east side of the harbor entrance. If an emergency exists, and with permission of the harbor master, shallow-draft vessels can anchor in the Mobile River above the Highway 90 Bridge, about 5 nmi north of the river's mouth.

2.3 AVAILABILITY OF OTHER HARBOR SERVICES

There are no military or civilian tugs under contract at Naval Station Mobile (Picard, 1992). Fuel for ships is readily available via contract fuel barge while docked at NAVSTA Mobile. Arrangements for JP-5 and DFM can be made by contacting Port Operations Dept.

Repair facilities abound in Mobile Bay. There are three large shipyards that can perform all types of repairs to deep-draft vessels. The facilities range from a 732 ft long dry dock with a capacity of 19,400 tons to a multitude of smaller installations. Salvage tugs, barges, derricks, pumps and diving outfits are available for virtually any type of work (U. S. Department of Commerce, 1980).

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT MOBILE

3.1 INTRODUCTION

By examining relevant characteristics of tropical cyclones such as track, speed of movement, intensity, month of occurrence, etc., some insight may be gained into their typical behavior. This background knowledge and understanding allows attention to be focused on those storms most likely to have a serious effect on Mobile. However, the historical behavior of storms and their impact should not be regarded as a reliable guide to the detailed behavior and impact of a particular storm as it approaches the port. Detailed attention should be paid to specific Navy and/or National Hurricane Center tropical cyclone warnings.

3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 nmi of Mobile is considered to represent a threat to the port. Table XXIV-1 contains a descriptive history of all tropical storms and hurricanes passing within 180 nmi of Mobile during the 107-year period 1886-1992. All of the tropical cyclone statistics used in this report for storms passing within 180 nmi of Mobile are based on the SAIC-generated data set used to compile Table XXIV-1. It should be noted that the center wind speeds marked by an asterisk (*) in column 7 are those observed at CPA and may not represent the tropical cyclone's strongest wind while within 180 nm of Mobile. An example of this is with Hurricane Andrew, storm index number 110. Andrew passed 178 nmi southwest of Mobile on a northwesterly track with center winds of 120 kt, eventually making landfall in Louisiana before moving northeastward across Louisiana and Mississippi. The center wind given for Andrew at CPA is only 30 kt because the storm had weakened after landfall and was on a northeasterly course (048°) at its CPA northwest of Mobile.

The gulf coast near Mobile is on the north shore of the Gulf of Mexico and is oriented perpendicular to normal cyclone tracks as they move more or less northward out of the tropics. The region's position between 25 and 30 degrees north latitude places it within the normal locus of tropical cyclone recurvature. The locus oscillates between latitudes 25°N and 35°N during the tropical cyclone season. This factor is significant since it is the character of tropical cyclones to slow and intensify during the recurvature stage. This is the most difficult stage of the tropical cyclone life cycle to actually forecast. Factors of

Table XXIV-1. Descriptive history of all tropical storms and hurricanes passing within 180 nmi of Mobile during the period 1886-1992.

1 STORM INDEX NUMBER	2 STORM NAME	3 YEAR	4 MONTH	5 DAY	6 STORM NUMBER FOR YEAR	7 MAXIMUM WIND AT STORM CENTER	8 CPA (CLOSEST POINT OF APPROACH)	9 DDD/SS.S DDD=HEADING SS.S=FORWARD SPEED AT CPA
1	NOT NAMED	1886	JUN	21	2	85	177 (ESE)	023/15.3
2	NOT NAMED	1887	JUL	27	2	85	77 (ESE)	019/11.0
3	NOT NAMED	1887	OCT	19	11	40*	13 (NW)	057/17.0
4	NOT NAMED	1889	SEP	23	6	84	28 (SE)	053/19.6
5	NOT NAMED	1892	SEP	12	4	40	45 (WNW)	035/18.2
6	NOT NAMED	1893	SEP	8	8	72	89 (WNW)	027/11.2
7	NOT NAMED	1893	OCT	2	10	72	19 (NW)	043/11.2
8	NOT NAMED	1894	AUG	8	1	44	38 (ENE)	337/ 4.4
9	NOT NAMED	1894	OCT	8	4	96	155 (SE)	037/ 7.4
10	NOT NAMED	1895	AUG	16	1	40	27 (WNW)	016/ 5.8
11	NOT NAMED	1896	JUL	7	1	75	104 (E)	003/ 4.2
12	NOT NAMED	1897	SEP	12	2	80	144 (SSW)	295/13.1
13	NOT NAMED	1898	AUG	3	1	35*	71 (NE)	310/11.5
14	NOT NAMED	1900	SEP	13	3	35	27 (WNW)	031/ 4.8
15	NOT NAMED	1901	JUN	14	1	35	4 (SSE)	342/ 9.3
16	NOT NAMED	1901	AUG	15	4	45*	53 (WNW)	015/ 6.3
17	NOT NAMED	1901	SEP	18	6	40	48 (ESE)	038/20.0
18	NOT NAMED	1902	OCT	10	4	47	7 (NE)	035/13.5
19	NOT NAMED	1903	SEP	14	3	55*	116 (ENE)	350/ 6.6
20	NOT NAMED	1904	NOV	3	5	35	10 (N)	053/13.7
21	NOT NAMED	1905	SEP	30	3	35	158 (WNW)	027/12.8
22	NOT NAMED	1905	OCT	10	5	33	114 (WNW)	023/14.4
23	NOT NAMED	1906	JUN	12	1	40	129 (E)	360/ 7.0
24	NOT NAMED	1906	SEP	27	5	102	24 (WSW)	339/ 8.7
25	NOT NAMED	1907	JUN	28	1	50	125 (SSE)	059/15.2
26	NOT NAMED	1907	SEP	22	2	35	62 (NW)	040/11.3
27	NOT NAMED	1907	SEP	28	3	43	95 (SE)	054/23.0
28	NOT NAMED	1909	JUL	1	2	30	60 (NNE)	289/12.6
29	NOT NAMED	1909	SEP	20	7	82	138 (WSW)	341/14.6
30	NOT NAMED	1911	AUG	12	1	63*	16 (NE)	319/ 6.6
31	NOT NAMED	1912	JUN	13	1	35	70 (NNW)	061/22.7
32	NOT NAMED	1912	SEP	14	3	63*	19 (W)	345/14.4
33	NOT NAMED	1914	SEP	18	1	35	17 (S)	255/12.5
34	NOT NAMED	1915	SEP	4	4	73	140 (E)	001/16.1
35	NOT NAMED	1915	SEP	30	5	60*	93 (WNW)	016/12.5
36	NOT NAMED	1916	JUL	5	1	115	43 (WSW)	329/10.4
37	NOT NAMED	1916	OCT	18	13	91	46 (E)	011/20.4
38	NOT NAMED	1917	SEP	28	3	100	59 (SE)	053/ 9.8
39	NOT NAMED	1919	JUL	4	1	38	50 (ENE)	346/ 6.3
40	NOT NAMED	1920	SEP	22	2	86	165 (WSW)	341/16.3
41	NOT NAMED	1922	OCT	17	3	37	14 (ENE)	338/ 4.4
42	NOT NAMED	1923	OCT	16	3	57*	165 (W)	350/20.3
43	NOT NAMED	1923	OCT	18	6	40	47 (W)	356/23.6
44	NOT NAMED	1924	SEP	15	4	68	101 (SE)	046/ 7.2
45	NOT NAMED	1926	AUG	26	3	65	173 (W)	349/ 5.9
46	NOT NAMED	1926	SEP	21	6	73	20 (SSW)	280/ 5.3
47	NOT NAMED	1928	AUG	15	2	40	145 (ENE)	342/11.4
48	NOT NAMED	1929	SEP	30	2	55*	149 (ESE)	012/ 5.2
49	NOT NAMED	1931	JUL	15	2	39	173 (WSW)	345/ 8.5
50	NOT NAMED	1932	SEP	1	3	68	12 (WSW)	319/ 8.6
51	NOT NAMED	1932	SEP	14	5	45	146 (SSE)	072/20.6
52	NOT NAMED	1932	SEP	20	6	34	173 (WNW)	019/31.2
53	NOT NAMED	1932	OCT	16	8	38	55 (NW)	045/14.4
54	NOT NAMED	1934	JUN	16	2	62*	150 (W)	360/11.0
55	NOT NAMED	1934	JUL	24	3	37	147 (S)	265/12.4

NOTES:
Datetimes are in UTC, winds are in knots, distances are in nautical miles. Parenthetical expression in column 8 gives bearing of storm from site at closest point of approach to site (CPA). Maximum winds are at time of CPA and did not necessarily occur at site. Asterisk (if any) after maximum wind indicates that storm was classified as a hurricane (at least 64 kts) somewhere within 180 nautical mile radius of site but not at CPA. Site location is 30.6°N, 88.1°W.

Table XXIV-1. Continued. Descriptive history of all tropical storms and hurricanes passing within 180 nmi of Mobile during the period 1886-1992.

1 STORM INDEX NUMBER	2 STORM NAME	3 YEAR	4 MONTH	5 DAY	6 STORM NUMBER FOR YEAR	7 MAXIMUM WIND AT STORM CENTER	8 CPA (CLOSEST POINT OF APPROACH)	9 DDD/SS.S DDD=HEADING SS.S=FORWARD SPEED AT CPA
56	NOT NAMED	1934	OCT	6	9	35	5 (E)	023/ 6.5
57	NOT NAMED	1935	NOV	7	6	34	166 (SSE)	063/ 9.9
58	NOT NAMED	1936	JUL	27	4	33	79 (WNW)	016/31.9
59	NOT NAMED	1936	JUL	31	5	50*	57 (ENE)	332/ 7.0
60	NOT NAMED	1937	SEP	20	6	40	83 (S)	075/13.5
61	NOT NAMED	1938	OCT	24	7	40	175 (SSE)	057/40.9
62	NOT NAMED	1939	JUN	16	1	34	1 (ESE)	337/12.7
63	NOT NAMED	1939	AUG	14	2	31*	59 (NE)	319/ 3.9
64	NOT NAMED	1939	SEP	26	3	30	124 (WSW)	028/ 6.5
65	NOT NAMED	1940	AUG	5	2	55	171 (S)	280/ 5.8
66	NOT NAMED	1941	SEP	12	1	35	156 (S)	280/ 3.5
67	NOT NAMED	1941	OCT	7	5	64	176 (E)	003/11.3
68	NOT NAMED	1943	JUL	25	1	55*	154 (S)	275/14.2
69	NOT NAMED	1944	SEP	10	6	32	44 (WNW)	031/17.8
70	NOT NAMED	1946	JUN	14	1	35	115 (S)	273/ 9.7
71	NOT NAMED	1947	SEP	19	4	98	73 (SW)	302/20.6
72	NOT NAMED	1947	SEP	8	5	33	25 (SSW)	309/11.1
73	NOT NAMED	1948	JUL	9	2	35	87 (SE)	048/11.2
74	NOT NAMED	1948	SEP	4	5	51*	82 (WNW)	014/12.5
75	NOT NAMED	1949	SEP	4	5	40	135 (WNW)	014/10.2
76	BAKER	1950	AUG	31	2	70	15 (E)	003/14.4
77	ALICE	1953	JUN	6	1	35	122 (E)	360/ 2.7
78	NOT NAMED	1953	SEP	19	7	60	114 (SSE)	068/ 8.8
79	FLORENCE	1953	SEP	26	8	78	84 (ESE)	027/ 9.5
80	BRENDA	1955	AUG	1	1	58	82 (SW)	319/ 7.4
81	NOT NAMED	1955	AUG	27	5	40	58 (SSW)	297/13.3
82	NOT NAMED	1956	JUN	14	1	40	124 (W)	358/16.4
83	FLOSSY	1956	SEP	24	7	80	46 (SSE)	066/11.5
84	NOT NAMED	1957	JUN	8	1	35	168 (SE)	042/24.6
85	DEBBIE	1957	SEP	8	5	35	76 (ESE)	028/11.9
86	ESTHER	1957	SEP	18	6	43	124 (W)	360/11.0
87	IRENE	1959	OCT	8	10	47	33 (ESE)	023/10.5
88	ETHEL	1960	SEP	15	6	48*	47 (W)	360/ 8.0
89	DORA	1964	SEP	11	6	35	165 (ENE)	342/ 4.4
90	HILDA	1964	OCT	4	10	52*	3 (ENE)	094/13.0
91	NOT NAMED	1965	JUN	15	1	45	84 (SE)	046/20.4
92	BETSY	1965	SEP	10	3	135	138 (SW)	315/18.5
93	DEBBIE	1965	SEP	30	5	30	55 (SW)	341/ 5.3
94	CAMILLE	1969	AUG	18	3	133	72 (WSW)	341/13.7
95	SUBTROP	1969	OCT	1	12	26	83 (E)	359/15.0
96	BECKY	1970	JUL	22	2	37	158 (ESE)	026/ 7.8
97	EDITH	1971	SEP	17	6	33	111 (NNW)	058/ 9.1
98	AGNES	1972	JUN	19	2	65	142 (ESE)	020/ 9.7
99	CARMEN	1974	SEP	8	6	118	178 (WSW)	329/ 8.3
100	ELOISE	1975	SEP	23	5	110	96 (ESE)	017/24.3
101	SUBTROP	1976	MAY	23	1	40	167 (SE)	051/22.5
102	BABE	1977	SEP	6	2	26*	93 (NW)	038/ 8.0
103	BOB	1979	JUL	11	2	40*	111 (WNW)	010/17.3
104	FREDERIC	1979	SEP	13	6	108	16 (SW)	337/11.8
105	ELENA	1985	SEP	2	5	102	37 (SSW)	292/14.0
106	JUAN	1985	OCT	31	10	55*	27 (SE)	037/15.9
107	KATE	1985	NOV	21	11	85	133 (ESE)	036/13.4
108	BERYL	1988	AUG	8	2	35	86 (SW)	141/ 2.9
109	FLORENCE	1988	SEP	10	7	60*	99 (WSW)	326/11.9
110	ANDREW	1992	AUG	27	1	30*	150 (NW)	048/10.3

NOTES:
Datetimes are in UTC, winds are in knots, distances are in nautical miles. Parenthetical expression in column 8 gives bearing of storm from site at closest point of approach to site (CPA). Maximum winds are at time of CPA and did not necessarily occur at site. Asterisk (if any) after maximum wind indicates that storm was classified as a hurricane (at least 64 kts) somewhere within 180 nautical mile radius of site but not at CPA. Site location is 30.6°N, 88.1°W.

difficulty include the rate of recurvature, the storm speed of movement subsequent to recurvature, and consequently, the storm's precise future position at a specific point in time.

The hurricane season along the Gulf Coast is late May through early November. During the 107-year period from 1886 through 1992 there were 110 tropical storms and hurricanes that met the 180 nmi threat criterion for Mobile, an average of about 1 per year. Figure XXIV-4 shows the monthly distribution of the 110 storms. The figure clearly shows that September is the month of greatest tropical cyclone threat to Mobile.

Figure XXIV-5 depicts the annual distribution of tropical storms and hurricanes passing within 180 nmi of Mobile. During 36 years of the 107-year history there have been no occurrences of tropical cyclones passing within 180 nmi of Mobile, including 10 of the last 13 years of record (1980-1992).

Table XXIV-2 shows the monthly frequency and motion history of the 110 tropical storms and hurricanes which passed within 180 nmi of Mobile during the period 1886-1992. The average movement for the storms at the closest point of approach (CPA) is 006 degrees at 12 kt. Approximately one of every three tropical cyclones passing within 180 nmi of Mobile is of at least minimum hurricane strength.

Figure XXIV-6 presents a graphical depiction of the number of tropical cyclones versus closest point of approach. The storm classification is based on the maximum wind near the storm center while that center was within 180 nmi of Mobile, not necessarily at CPA. The sloping lines represent mathematical fits to the data points for the various intensity classifications. The average radii of maximum wind for 34-, 100- and 140-kt tropical cyclones at Mobile are 25.2, 23.6, and 20.7 nmi respectively.

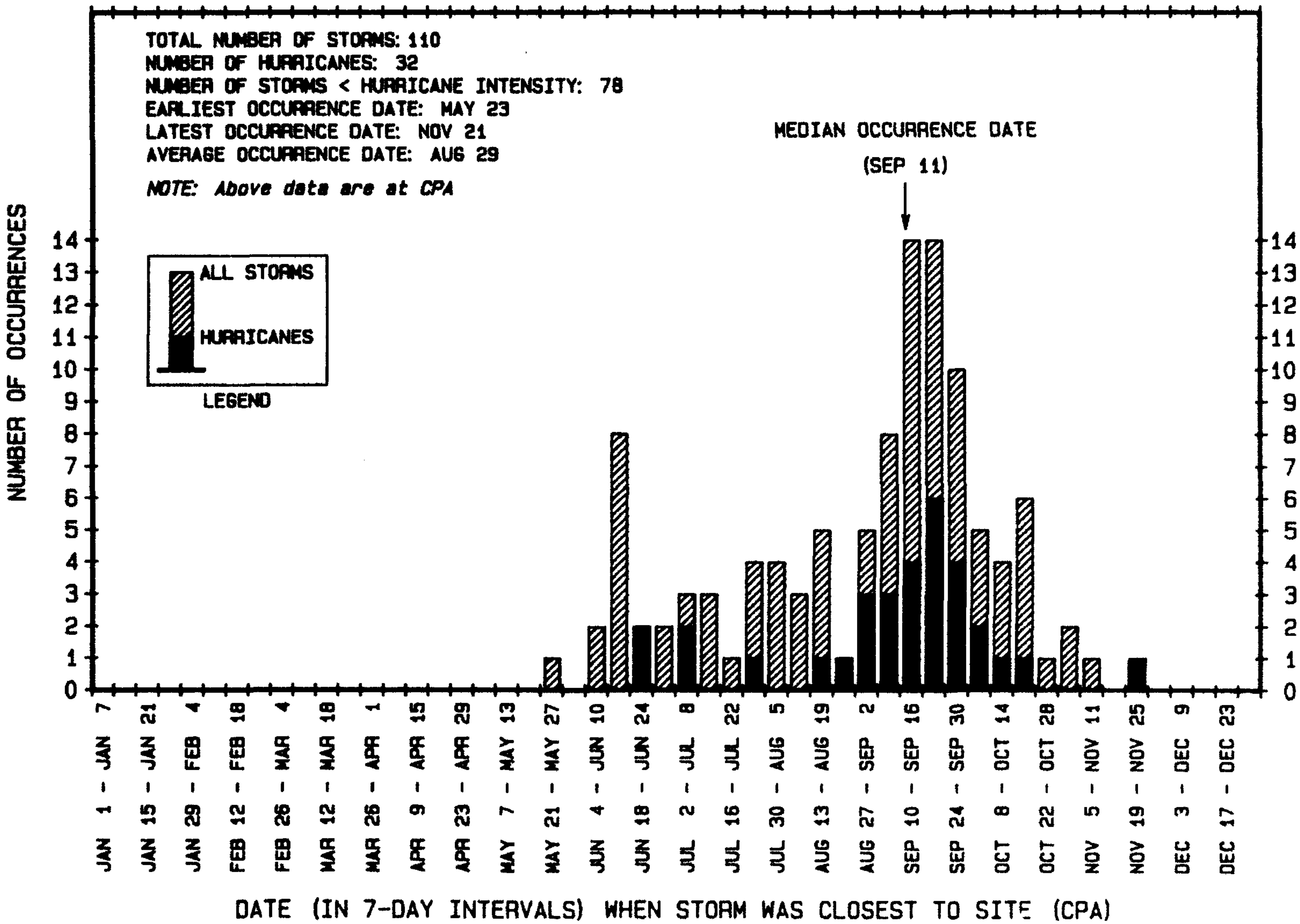


Figure XXIV-4. Monthly distribution of all tropical storms and hurricanes passing within 180 nmi of Mobile during the 107 year period 1886-1992.

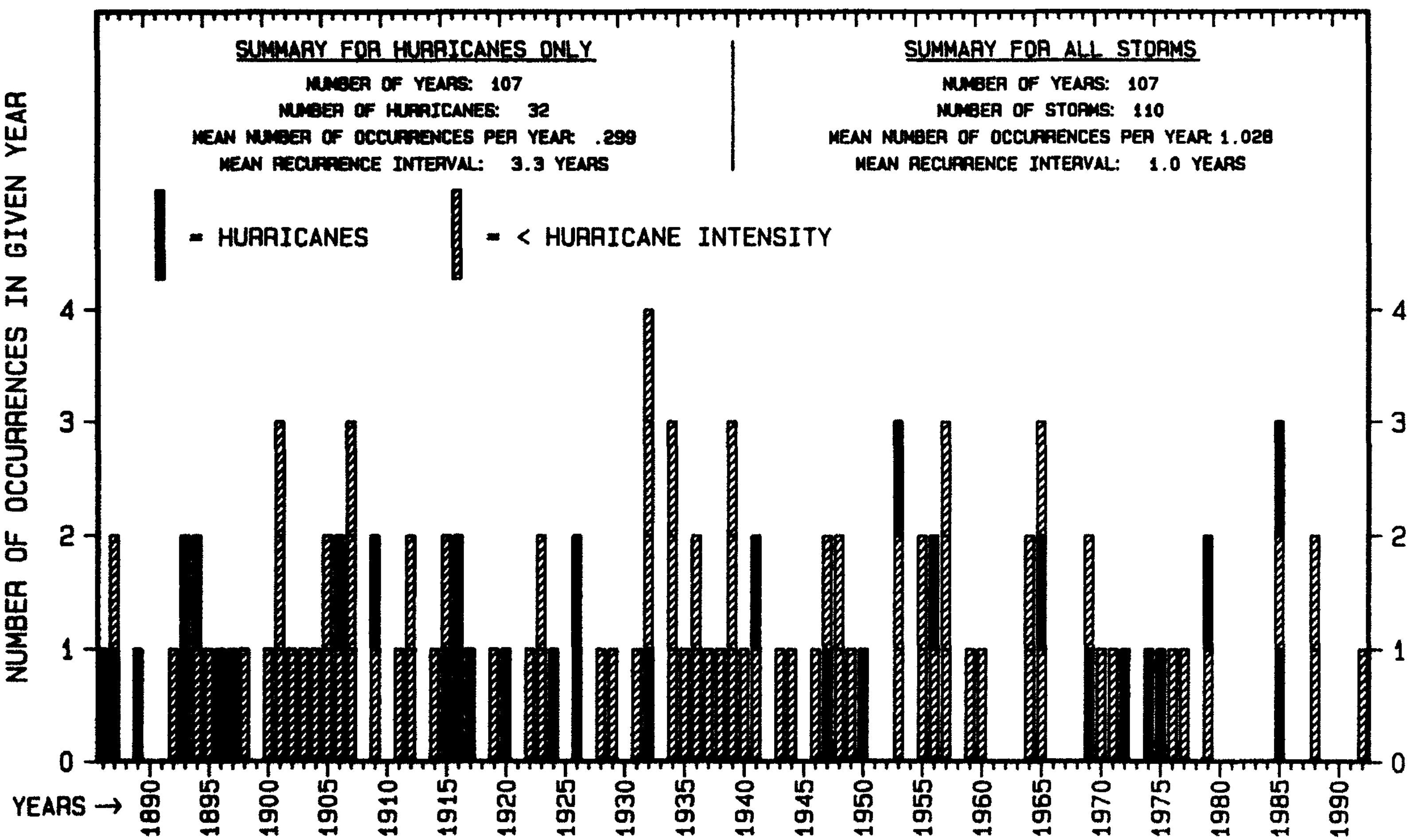


Figure XXIV-5. Chronology of all tropical storms and hurricanes passing within 180 nmi of Mobile during the 107 year period 1886-1992. Storm intensity is determined at time of closest point of approach (CPA) to Mobile.

Table XXIV-2. Frequency and motion of tropical storms and hurricanes passing within 180 nmi of Mobile over the 107 year period 1886-1992.

Total number of storms passing within 180 n mi	0	0	0	0	1	14	12	15	48	17	3	0	110
Number of storms having at least hurricane intensity at CPA	0	0	0	0	0	2	3	3	19	4	1	0	32
Number of storms less than hurricane intensity at CPA	0	0	0	0	1	12	9	12	29	13	2	0	78
Average heading (degs) towards which storms were moving at CPA	---	---	---	---	*	007	351	339	004	027	*	---	006
Average storm speed (knots) at CPA	---	---	---	---	*	13	12	8	12	15	*	---	12
Month when storm was at CPA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR

* indicates insufficient storms for average direction and speed computations.

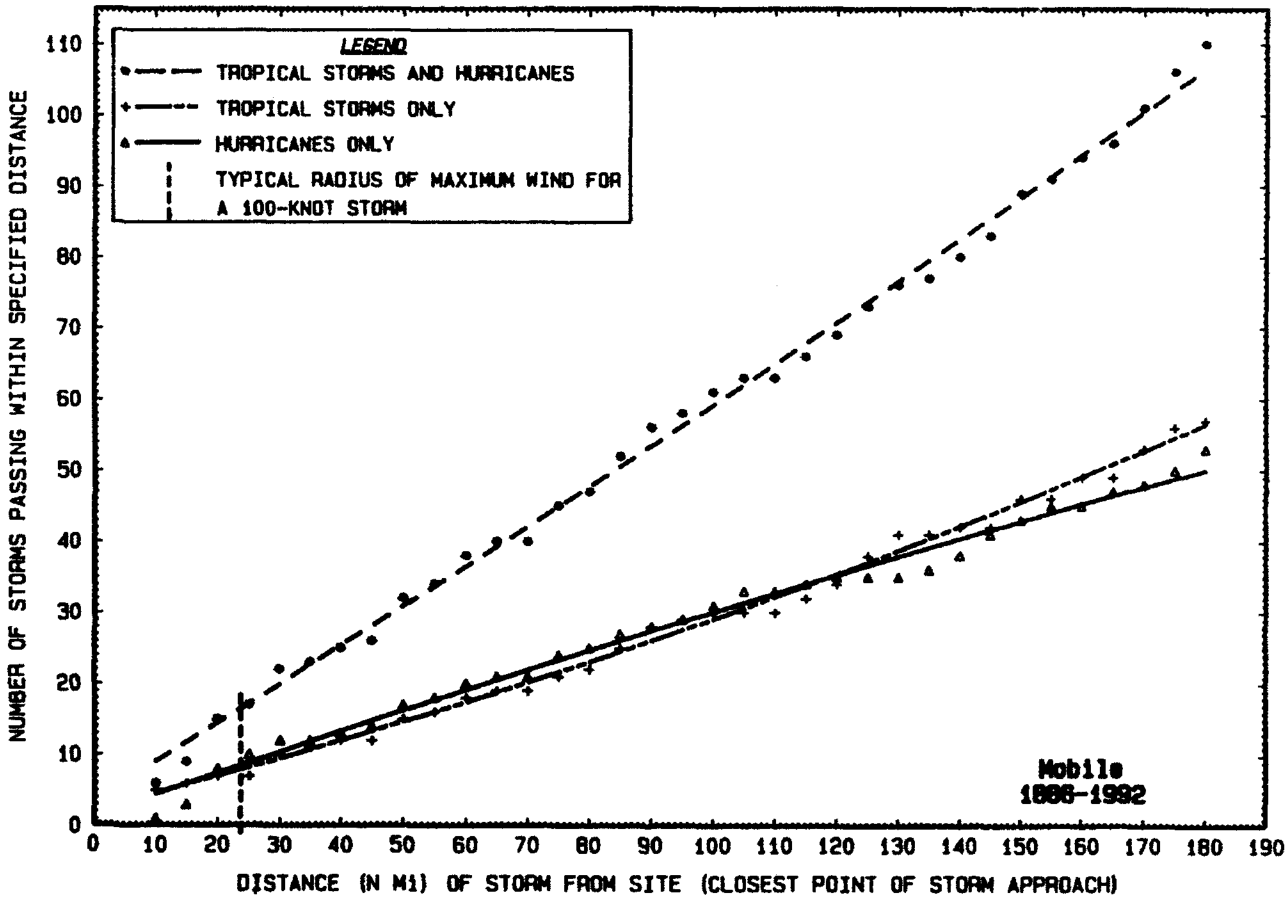


Figure XXIV-6. Number of tropical cyclones passing at various distances from Mobile over the 107-year period of record. Tropical storm or hurricane classification is based on maximum wind near storm center while that center was within 180 nmi of Mobile and not necessarily at CPA. Sloping lines represent mathematical fit to data points. Average radius of maximum wind for 34, 100 and 140 kt storms at Mobile are 25.2, 23.6, and 20.7 nmi respectively.

Figure XXIV-7 displays the storms as a function of the compass octant from which they approached Mobile. It is evident that the major threat from tropical cyclones is from the southeast clockwise through southwest. It should be noted that the that the approach direction is determined at CPA and may not represent the initial approach direction of the tropical cyclone toward Mobile.

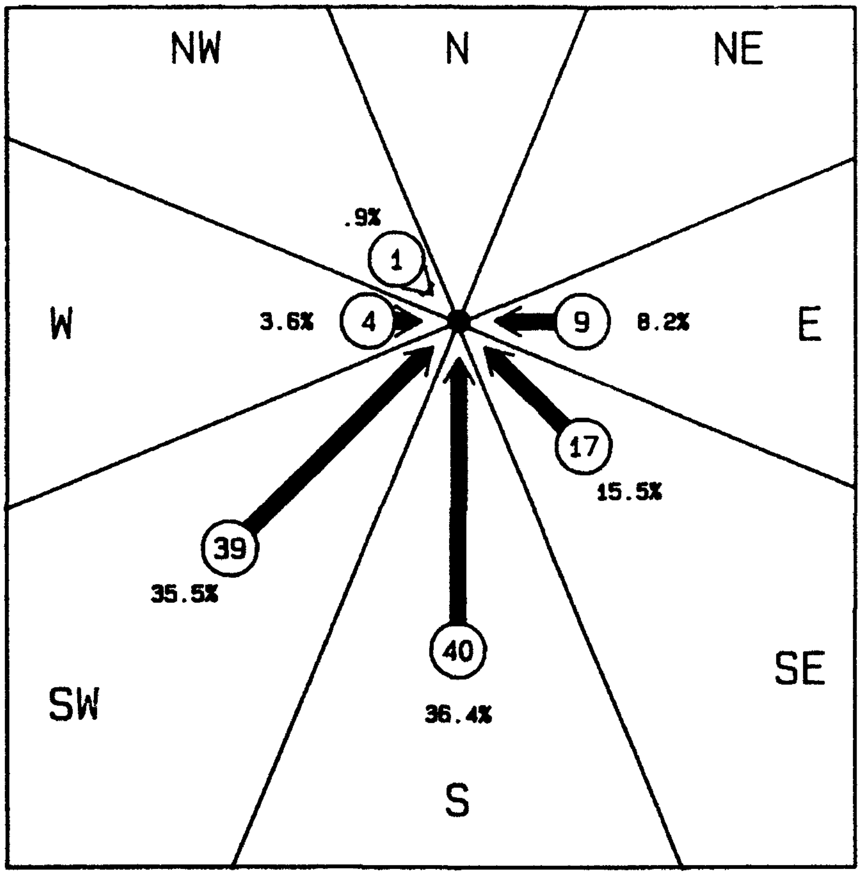


Figure XXIV-7. Directions of approach for 110 tropical cyclones passing within 180 nmi of Mobile during the 107-year period of record. Length of directional arrow is proportional to the number of storms given in the circles of each octant. Approach directions are determined at CPA.

Figures XXIV-8 through XXIV-11 provide information on the probability of remote tropical cyclones passing within 180 nmi of Mobile and the average time to CPA. A comparison of the figures shows some distinct differences in threat axis according to time of year. The least active period, November through June, shows the major threat axis to be from nearly due south, across the Gulf of Mexico and then southeastward through the Yucatan Channel into the western Caribbean Sea. The threat axis for the July and August period is significantly different in that it has two lobes, one extending southeastward through the Straits of Florida before progressing eastward to the subtropical North Atlantic Ocean at about 25°N latitude and the second axis extending south-southeastward through the Yucatan Channel into the Caribbean Sea.

By September the major axis has shifted southward through the Yucatan Channel into the Caribbean Sea, thence eastward north of South America along about 15°N. The primary October threat axis has shifted to the Gulf of Campeche west of the Yucatan Peninsula, indicating that the greatest threat is from recurving storms entering the Gulf of Mexico from the Caribbean Sea or from storms originating or passing through the Gulf of Campeche. Two storms of record initially formed in the Pacific Ocean south of Mexico and crossed the rather narrow portion of Mexico near the Gulf of Tehuantepec into the Gulf of Campeche before moving northward across the Gulf of Mexico. A secondary axis extends eastward near 20°N just north of Cuba, Hispaniola and Puerto Rico.

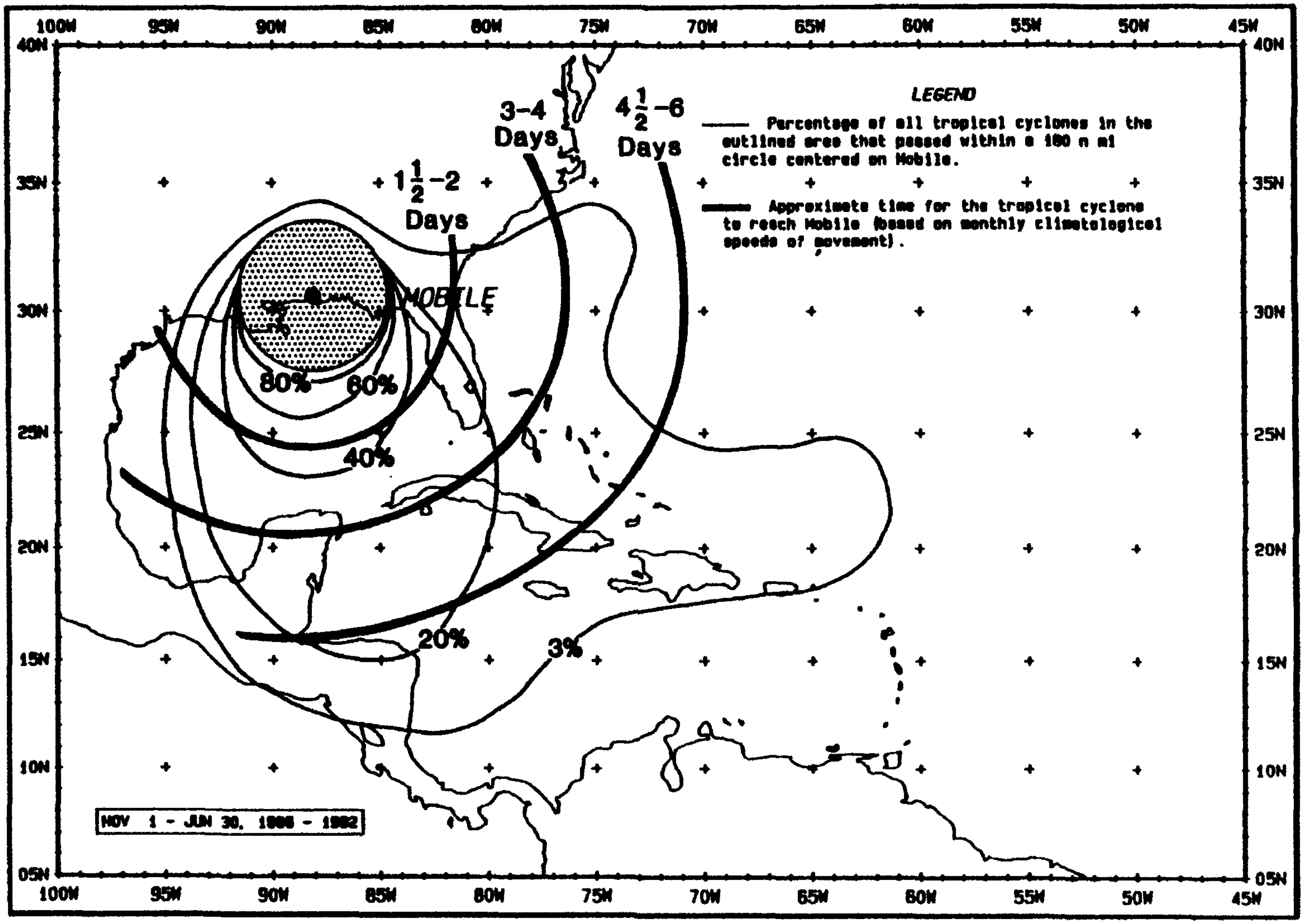


Figure XXIV-8. Probability that a tropical storm or hurricane will pass within 180 nmi of Mobile (circle), and approximate time to closest point of approach, during the period November through June (based on data from 1886-1992).

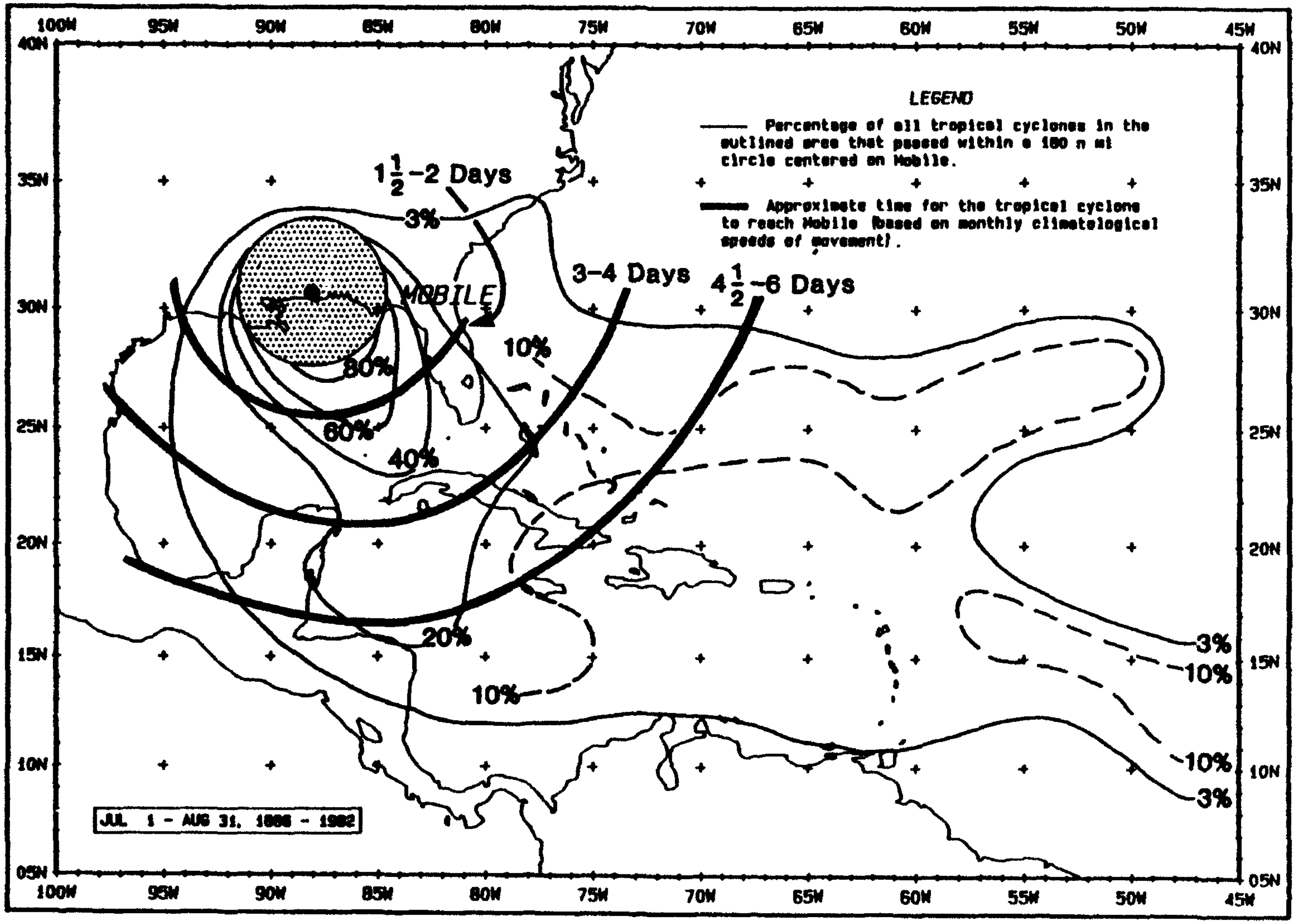


Figure XXIV-9. Probability that a tropical storm or hurricane will pass within 180 nmi of Mobile (circle), and approximate time to closest point of approach, during July and August (based on data from 1886-1992).

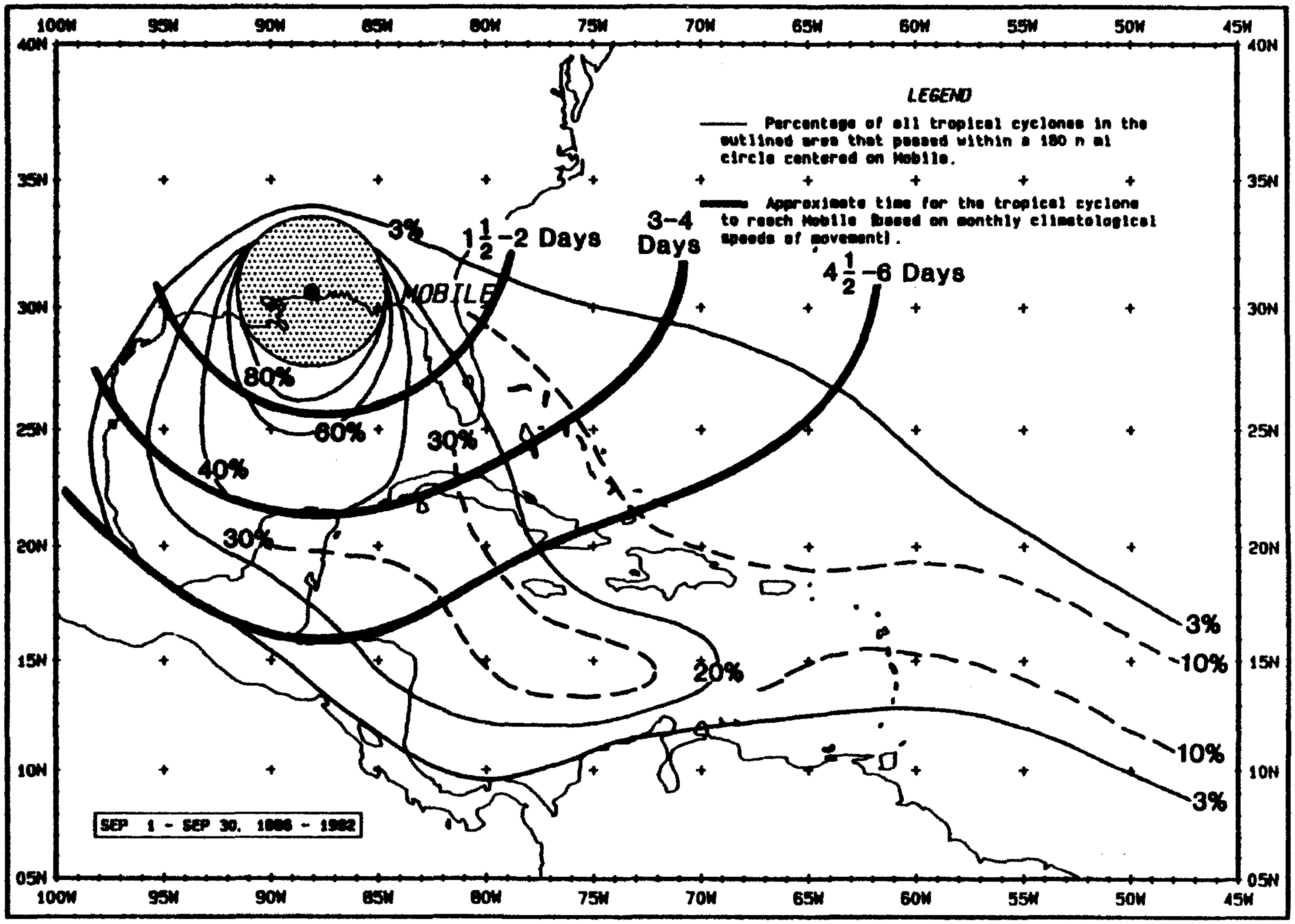


Figure XXIV-10. Probability that a tropical storm or hurricane will pass within 180 nmi of Mobile (circle), and approximate time to closest point of approach, during September (based on data from 1886-1992).

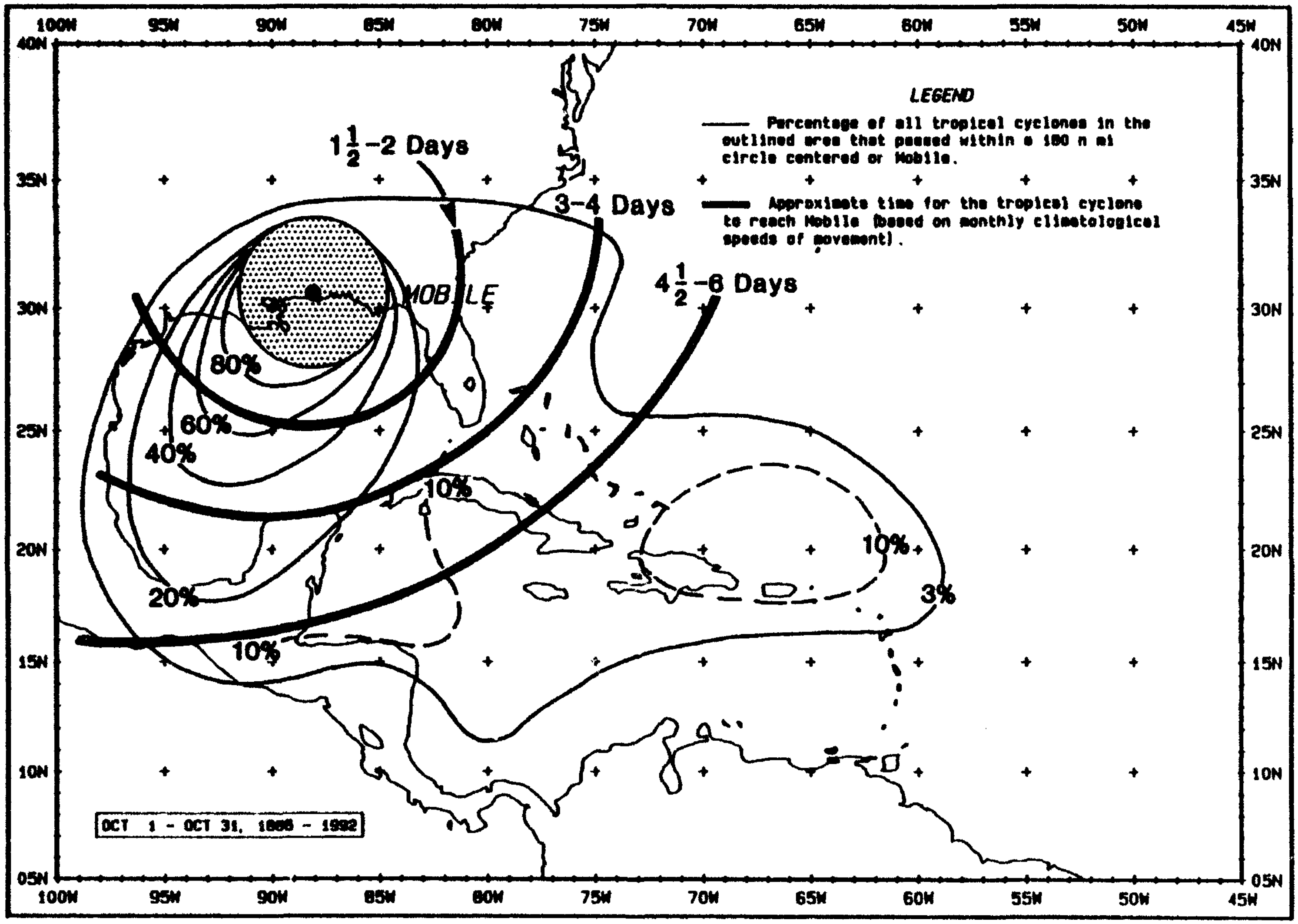


Figure XXIV-11. Probability that a tropical storm or hurricane will pass within 180 nmi of Mobile (circle), and approximate time to closest point of approach, during October (based on data from 1886-1992).

3.3 ENVIRONMENTAL EFFECTS

3.3.1 WIND AND TOPOGRAPHY

The relatively low-lying topography surrounding Mobile Bay affords little protection; Naval Station Mobile is exposed to the full effects of tropical cyclone winds. History has shown that the region is susceptible to strong winds and associated weather phenomena. Table XXIV-3 lists wind and related weather data recorded during specific storm occurrences at Mobile. Wind speeds recorded at Mobile International Airport have been adjusted upward to better reflect conditions at the site of the Naval Station, using the approach of S. A. Hsu, Boundary Layer Meteorology, 1981. The adjustment factors are: 1.35 for 22-33 kt, 1.3 for 34-63 kt, and 1.2 for 64 kt or greater.

Table XXIV-3. Center data and related weather associated with specific hurricanes which passed within 180 nmi of Mobile.

HURRICANE DATA				RELATED WX IN MOBILE AREA		
DATE	SOA (KT)	DIR/CPA (N.MI)	CNTR (KT)	MAX WIND AND GUST (KT)*	SURGE HT (FT)	MAX PRECIP 24HR/6HR (IN.)
9/18/47	21	SW 99	102	NE 38+68		
9/4/48	12	W 97	65	SSW 40+56		2.96/1.62
8/30/50	14	OVERHEAD	82	36+47		3.73
9/24/56	11	SE 41	74	57+65		4.57/2.31
9/18/57	12	W 141	33	46+68		4.83/1.68
9/15/60	8	W 58	63	41+56		2.75
10/4/64	9	NW 24	91	52+72		1.96
9/9/65	14	W 42	109	38+49		2.19
8/18/69	13	W 82	115	49+80	6.5	5.12/1.85
9/12/79	12	W 32	90	72+101		8.23/0.32
9/2/85				52+68		

* **NOTE:** Wind speeds for the Naval Station are based on Mobile International Airport winds adjusted upward by factors of 1.35 (22-33 kt), 1.3 (34-63 kt), and 1.2 (≥ 64 kt) (Hsu, 1981).

In addition to the data given in Table XXIV-3, U. S. Coast Pilot 5 (1980) states: "While a tropical cyclone may be expected to affect this region about every 2 years on average, destructive storms have been infrequent on Mobile Bay during this century. Eight hurricanes have crossed the coast near Mobile Bay since 1900. In September 1979, hurricane Frederic, generating 115-knot sustained winds and a 12-foot storm tide (above mean sea level), became the first hurricane since 1926 to directly strike Mobile. During the storm, Dauphin Island reported gusts to 126 knots."

3.3.2 STORM SURGE AND TIDES

Although wind damage from a tropical cyclone can be severe, storm surge may pose a greater threat to life and property. Storm surge may be visualized as a raised dome of water, moving with the storm, and centered a few miles to the right of its path. The dome height is related to local pressure (i.e., a barometric effect dependent on the intensity of the storm) and to local winds. Other significant contributing factors are storm speed, direction of approach, bottom topography, and coincidence with astronomical tide.

The worst combination of circumstances (Harris, 1963, and Pore and Barrientos, 1976) would include:

(1) An intense storm approaching perpendicular to the coast with the harbor within 30 nmi to the right of the storm's track.
(2) Broad, shallow, slowly shoaling bathymetry.
(3) Coincidence with high astronomical tide.

The waters of the Gulf coast near Mobile meet the bathymetry criteria. This factor, coupled with the facts that Mobile Bay is large, relatively shallow over most of its extent, and has a rather large entrance open to seaward, renders Mobile Bay vulnerable to storm surges.

Research in storm surge prediction techniques has led to the development of an advanced storm surge forecasting tool. Developed by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service, it is known by its acronym "SLOSH", which stands for Sea, Lake, and Overland Surges from Hurricanes (Jelesnianski and Chen, 1979). The Tri-state Hurricane Evacuation Study, Mississippi, Alabama, and Florida contains charts which detail the storm surge levels for the states listed. It also lists historical hurricane tide elevations for Mobile as shown in Table XXIV-4.

Table XXIV-4. Historical record of hurricane tide elevations at Mobile, Alabama.

DATE	HEIGHT ABOVE MEAN SEA LEVEL
SEPTEMBER 27, 1906	9.9 FT
JULY 5, 1916	10.8 FT
SEPTEMBER 10, 1965	4.8 FT
AUGUST 18, 1969	7.4 FT

The SLOSH model calculates storm surge values for five storm intensities, each corresponding to a category on the "Saffir/Simpson Scale". This scale, shown in Table XXIV-5, was developed by Herbert Saffir and Dr. Robert H. Simpson.

Table XXIV-5. Saffir/Simpson scale.

	CENTRAL PRESSURE		WIND		
SCALE NO.	MB	INCHES	MPH	KNOTS	DAMAGE
1	>980	>28.94	74-95	64-83	Minimal
2	965-979	28.50-28.91	96-110	84-95	Moderate
3	945-964	27.91-28.47	111-130	96-113	Extensive
4	920-944	27.17-27.88	131-155	114-135	Extreme
5	<920	<27.17	155+	135+	Catastrophic

Figures XXIV-12 through XXIV-16 show the extent of storm surge intrusion on the land area adjacent to Naval Station Mobile for hurricane categories 1 through 5. These figures have been adapted from Appendix A of Tri-state Hurricane Evacuation Study, Mississippi, Alabama and Florida (Dept of the Army, 1986).

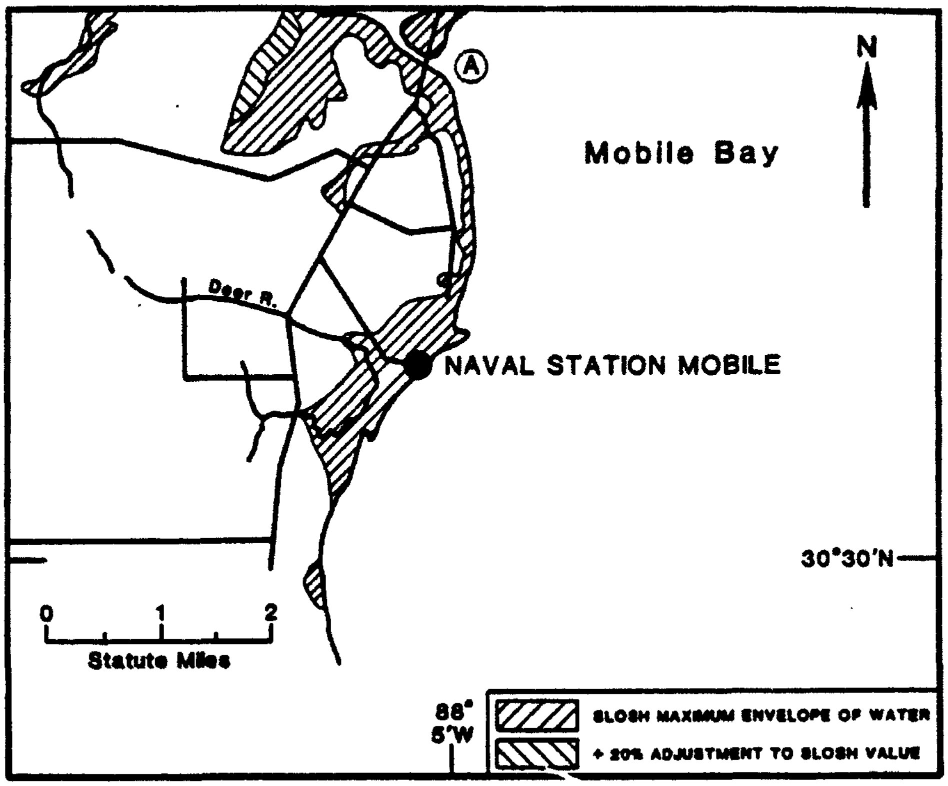


Figure XXIV-12. Category 1 storm surge contours. Adapted from Dept of the Army, 1986.

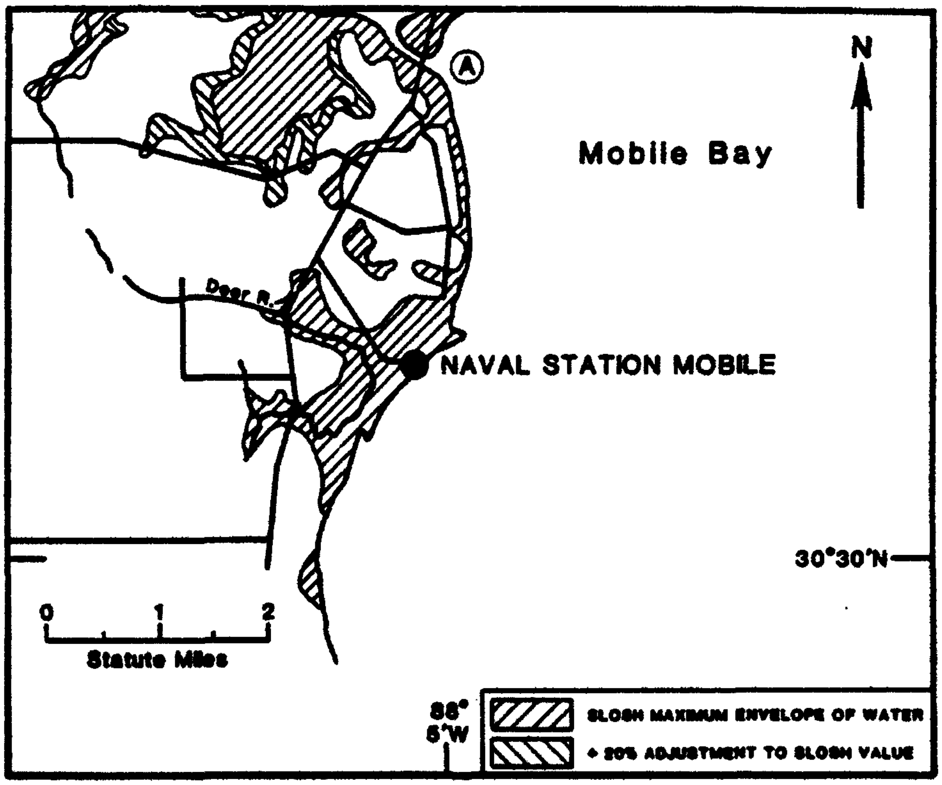


Figure XXIV-13. Category 2 storm surge contours. Adapted from Dept of the Army, 1986.

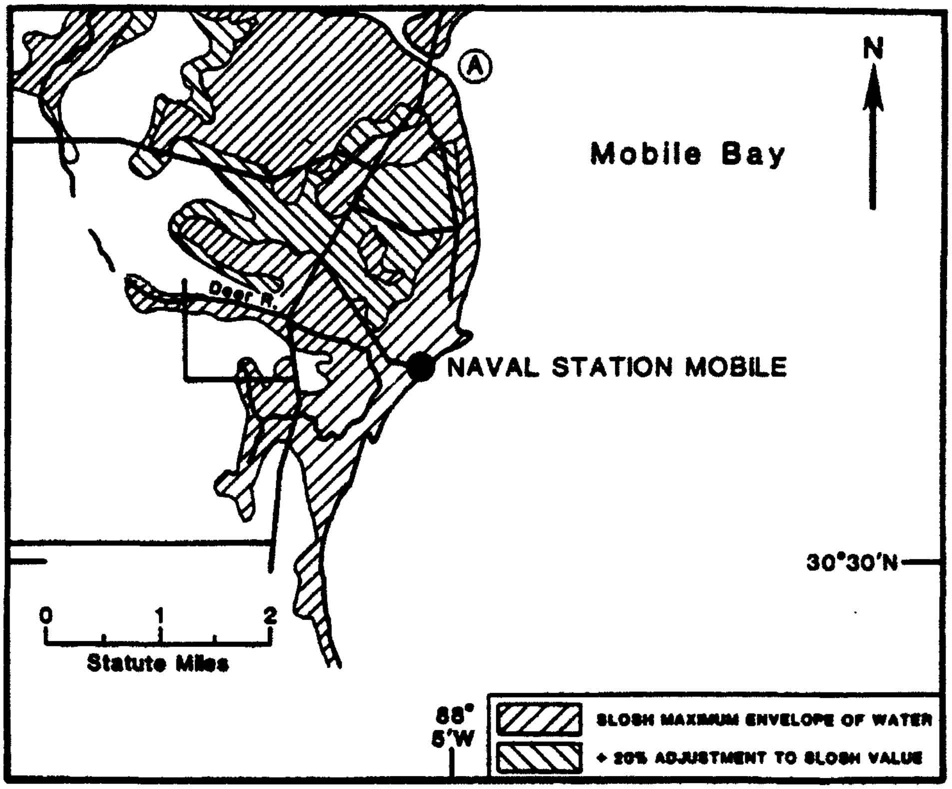


Figure XXIV-14. Category 3 storm surge contours. Adapted from Dept of the Army, 1986.

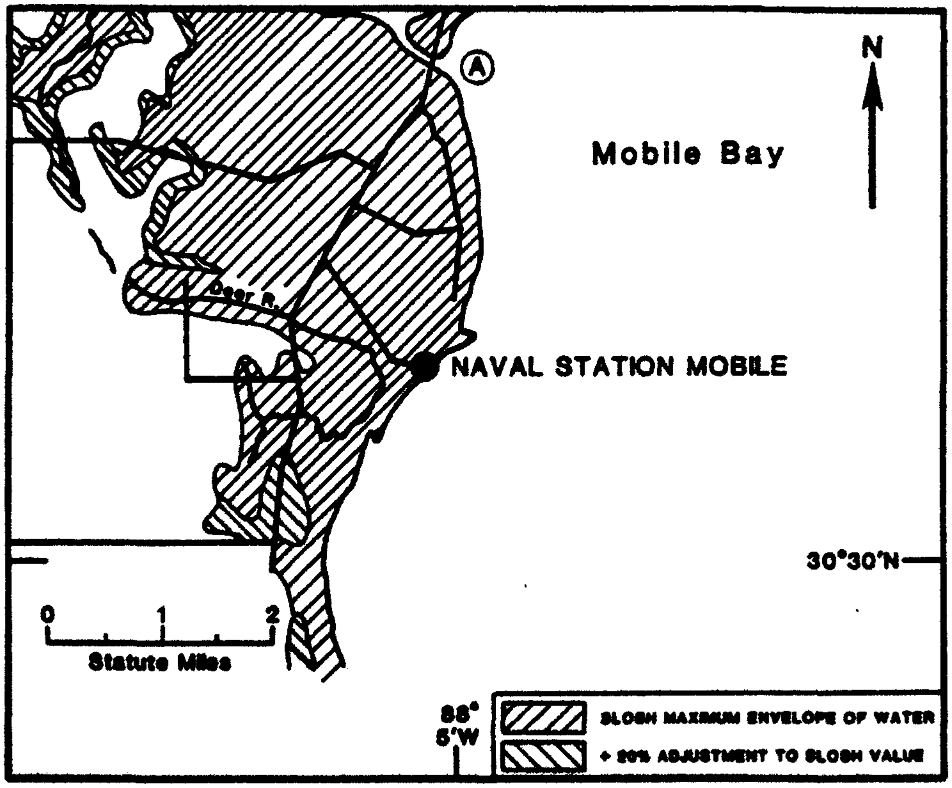


Figure XXIV-15. Category 4 storm surge contours. Adapted from Dept of the Army, 1986.

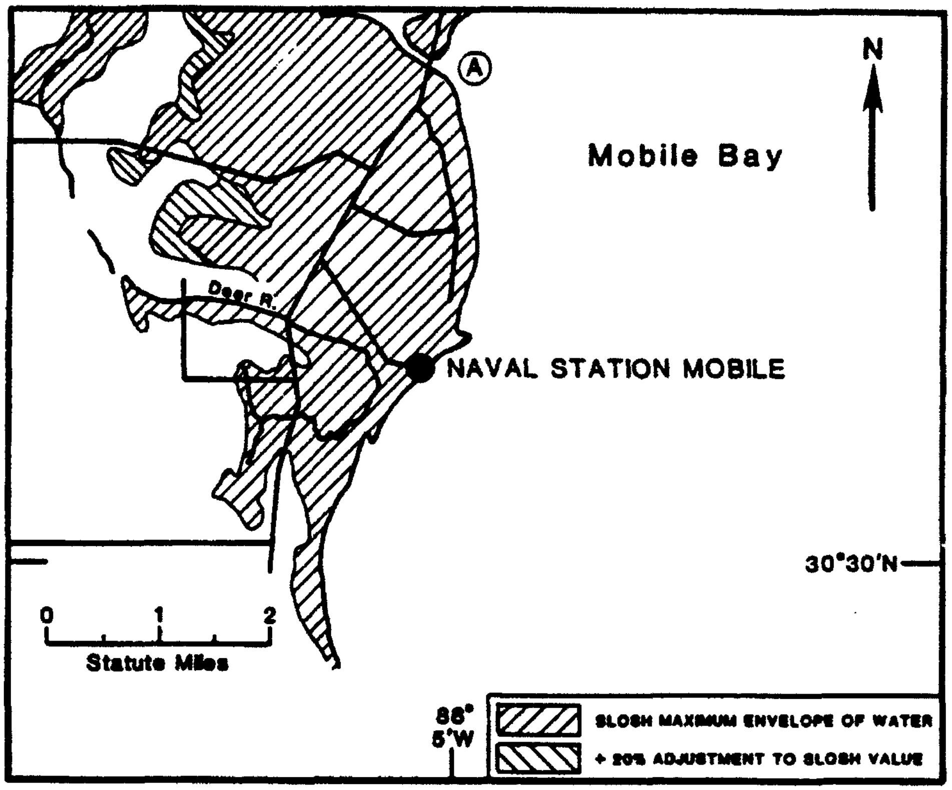


Figure XXIV-16. Category 5 storm surge contours. Adapted from Dept of the Army, 1986.

Figures XXIV-12 through XXIV-16 only show the extent of storm surge intrusion, with anticipated surge heights not included. Since the station is built on land with elevations only 12 to 14 ft above sea level, it is obvious that the entire station is at risk of inundation with the passage of only a moderately strong storm through the area.

While no forecast heights are available for the exact location of Naval Station Mobile, the <u>Tri-state Hurricane Evacuation Study</u> for Mississippi, Alabama and Florida indicates the storm surge heights listed in Table XXIV-6 are to be expected less than 3 miles north of the Naval Station at the area indicated by the letter "A" in figures XXIV-12 through XXIV-16.

Table XXIV-6. Storm surge heights for the location indicated by the letter "A" in Figures XXIV-12 through XXIV-16. Adapted from Department of the Army (1986).

STORM CATEGORY	SLOSH SURGE HEIGHT IN FEET ABOVE M.S.L.	ADJUSTED SURGE HEIGHT IN FEET ABOVE M.S.L.
1	4.8	5.6
2	7.7	9.1
3	11.0	13.0
4	15.9	18.9
5	14.4	17.1

4. THE DECISION TO EVADE OR REMAIN IN PORT

Naval Station Mobile is within Commander Naval Base Charleston's Sub-region "C", and is covered by Chief of Naval Education and Training (CNET) Instruction 3140.1, subject: DESTRUCTIVE WEATHER BILL FOR COMNAVBASE CHARLESTON SUB-REGION "C". Naval Air Station, Pensacola, Florida is the Sub-Regional Planning Agent (SRPA) and is responsible for setting Hurricane and Tropical Storm Conditions of Readiness for individual warning areas located in Sub-Region "C". Naval Oceanography Command Detachment (NAVOCEANCOMDET), Pensacola is responsible for issuing destructive weather warnings.

4.1 THREAT ASSESSMENT

The tropical cyclone threat analysis presented in Section 3 of this evaluation indicates that Mobile Bay is at considerable risk from both storm surge and high wind. Although some shelter from southerly winds would be provided on the north side of the 2-story pier, with similar protection on the south side of the pier from northerly winds, <u>the absence of sheltered berths or anchorages makes evasion at sea the safest course of action for all seaworthy deep-draft vessels</u>. Evasion should be initiated as soon as it is established that a particular tropical cyclone poses a threat to Mobile Bay. Early assessment of each potential threat is essential. Assessment should be related to the setting of hurricane conditions of readiness by military and civil authorities based on current advisories and forecasts issued by the Navy and National Weather Service, as well as climatology.

Individual storm intensity and speed of movement will affect the potential for damage which can be expected from any given storm. As a general rule, any intense tropical storm or hurricane approaching from the Gulf of Mexico such that Mobile is located in the dangerous right front quadrant of the storm can result in severe wind and storm surge conditions.

The pier at Naval Station Mobile extends east-southeastward from the shore. Winds from the south-southeast will raise the largest wind waves because of the fetch in that direction (Perryman, 1991). A small island approximately 500 yards east of the pier may afford limited protection from the southeast.

The biggest problem will be flooding. The maximum storm surge generated by the SLOSH model for the port area is 18.9 ft with a Category 4 storm (Table XXIV-6), but there is flooding indicated for the area around the base under <u>all</u> categories. In addition, the Naval station is located on wetlands only 12 to 14 ft above sea level and the ground remains quite saturated with standing pools of water as part of the "natural habitat," so any significant rainfall will add to the problems of storm surge (Perryman, D., 1991)

4.2 EVASION AT SEA

Evasion at sea is the recommended course of action for all seaworthy deep draft vessels when Mobile is under threat from a strong tropical cyclone. Timing of the decision to evade is affected by:

(1) The forward speed of the tropical cyclone.

(2) The radius of hazardous winds and seas that can impact on a vessel's ability to reach open water and then maneuver to evade.

(3) The elapsed time to make preparations to get underway.

(4) The elapsed time to reach open water.

For example:

The worst potential problem would be a hurricane moving directly toward Mobile from the south. The frigates which will be based at the Naval Station are gas turbine powered, and have minimal cold iron problems, but still require a few hours to get underway. If 6 hours are required to make preparations for sortie after the decision to evade at sea is made, and another 2-3 hours (about 24 nmi at 9-10 kt SOA) are required to transit to deep water, a hurricane approaching at 10 kts will be approximately 80 nmi closer to Mobile by the time open water is reached. When the radius of strong winds likely to hamper operations, about 200 nmi, is added, it gives 280 nmi (or 28 hours) as the minimum hurricane displacement from Mobile when the sortie must be started if heavy weather is to be avoided (Picard, 1992). A greater margin may be applicable depending on an increased storm speed of advance, if the radius of strong winds is larger, or if there is increased ship preparation or decreased speed capabilities.

Hurricane Condition III is set when hurricane force (≥ 64 kt) winds are possible within 48 hours. It is apparent that the decision to sortie should be made soon after setting Hurricane Condition III. Although at this time the storm center may be more than 500 nmi distant, it should be remembered that the 48-hour forecast position average error is greater than 200 nmi.

Consequently, the storm center may be much nearer (or farther) from Mobile or significantly left or right of its forecast track than the 48-hour forecast indicates. A departure soon after Hurricane Condition III is set is suggested as the wisest and safest course of action. Later departures wager the accuracy of information on the storm's behavior against mounting risks of heavy weather damage.

Once sea room is attained, the tactics employed will depend on the location of the threatening tropical cyclone, its speed of advance, and its direction of movement. Up-to-date information is essential if sound decisions are to be made. Tropical cyclone location and intensity information based on today's satellite technology is accurate and timely. Forecasts and warnings are issued at 6-hourly intervals and updated as necessary to reflect important changes in position, intensity, and movement. Ship masters with access to these advisories/warnings are in the best possible position to modify evasion routes and tactics to successfully evade the storm. While a cardinal rule of seamanship is to <u>avoid the dangerous right-hand semicircle</u> of a hurricane, the rule may have only limited application in the eastern Gulf of Mexico. A storm approaching from the southwest effectively limits the evasion options to a course to the southeast quadrant. Since there are no other viable sortie options, the ship is placed in the potentially more dangerous right-hand semicircle.

The following guidelines are offered.

(1) Tropical cyclone approaching from east or southeast: Depart early and steam southwest to increase distance from storm, taking advantage of northerly winds and seas. Mobile's location east of the Mississippi River delta dictates that about 50 nmi must be travelled once the Gulf of Mexico is reached before open water to the southwest is attained. This factor makes an early departure even more critical to avoid getting trapped between the approaching storm and the delta.

(2) Tropical cyclone approaching from west or southwest: Sortie early to avoid head winds and seas and steam southeast.

This option may place the ship in the dangerous right hand semicircle of the storm, but an early departure will allow sufficient time to evade the storm before it reaches the ship.

(3) Tropical cyclone approaching from south: WORST CASE! Evasion tactics must be based on the latest forecast position and movement. While precautions must be taken to avoid the strong winds of the storm's right semicircle, limited directional options may offer little choice other than taking a course that enters the dangerous semicircle. If such a course is taken, it must be started early and pursued with all deliberate speed in order to avoid strong head winds and high seas. Early departure is essential if heavy weather is to be avoided. Delaying departure for any reason will seriously restrict evasion options. Be alert for storm recurvature to the northeast!

4.3 RETURNING TO PORT

The damage and disarray at a port resulting from a tropical cyclone strike may include navigation hazards such as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Erosion and restructuring of barrier islands and channels is extremely likely in the Gulf coast area of Mobile. Due caution should be exercised following tropical cyclone passage. Naval Station services may be so damaged as to preclude offering even minimal services.

4.4 REMAINING IN PORT

Little protection from wind is available at Naval Station Mobile, and no protection from storm surge exists. For Condition 1-3 status, if a vessel cannot get underway due to mechanical problems, it should be ballasted down as much as possible and secured to the dock with sufficient mooring lines, including spring lines, to withstand predicted wind forces, yet allow water height fluctuations of the predicted amounts. For Condition 4 and 5, recommend vessel be moved to the Alabama State docks in Mobile.

If the decision is made to remain in port it should be borne in mind that the vessel will be exposed to dangers beyond that of wind and storm surge. Vessels in other portions of Mobile Bay may break loose from their moorings and become floating hazards. Also, there is a danger that a damaged or sunken vessel could effectively block the narrow ship channels and trap shipping at the pier for some time after a storm has passed.

4.5 ADVICE TO SHALLOW DRAFT VESSELS

Since the Naval Station is constructed on land which is only 12 to 14 ft above sea level, the usual precaution of removing the small craft from the water and securing them at least 20 ft above sea level to avoid possible high water does not apply unless they can be moved from the Naval Station.

As was stated in Section 2.2 above, if an emergency exists, and with permission of the harbor master, shallow-draft vessels can anchor in the Mobile River above the Cochrane (Highway 90) Bridge, some 5 nmi north of the mouth of the river (U. S. Department of Commerce, 1980). In 1985, the old vertical lift span bridge was removed and a fixed bridge with a design clearance of 140 feet was constructed. An overhead power cable of unspecified clearance crosses the river at the bridge.

If it is decided that small craft should seek shelter along the shores of the Mobile River north of Mobile, several precautions should be taken. Virtually no protection is afforded except near lee shores, and even that is minimal. The following extract from U. S. Coast Pilot 5 (1980) is relevant:

> *"Hurricane Moorings. On receiving advisory notice of a tropical disturbance small boats should seek shelter in a small winding stream whose banks are lined with trees, preferably cedar or mangrove. Moor with bow and stern lines fastened to the lower branches; if possible snug up with good chafing gear. The knees of the trees will act as fenders and the branches having more give than the trunks, will ease the shocks of the heavy gusts. If the banks are lined only with small trees or large shrubs, use clumps of them within each hawser loop. Keep clear of any tall pines as they generally have shallow roots and are apt to be blown down."*

Using open water anchorages to ride out the passage of a tropical cyclone is extremely hazardous. Virtually no protection is afforded except near lee shores. Wind wave activity can be quite destructive, not to mention the hazards of floating debris resulting from the effects of wind waves, high water, and high winds.

The prudent small boat operator will have selected several potential havens beforehand in which to take shelter in various tropical cyclone threat situations. He will proceed to his haven well in advance to avoid the chaos and congestion endured by his fellow boaters who delay until the onset of destructive conditions is imminent.

REFERENCES

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U. S. Department of Commerce, 1980: United States Coast Pilot 5, Atlantic Coast: Gulf of Mexico, Puerto Rico, and Virgin Islands. National Oceanic and Atmospheric Administration, National Ocean Survey, Washington, DC.

PORT VISIT INFORMATION

November 1991. NRL Meteorologists Dennis Perryman and Roland Picard met with CWO J. Smith, Port Operations Officer and LT Ron Williams of Naval Station Mobile to obtain some of the information contained in this report.

XXV. NS PASCAGOULA, MISSISSIPPI

SUMMARY

The hurricane season poses a serious threat to Naval Station Pascagoula. During the 107-year period from 1886-1992, an average of one tropical cyclone or hurricane has passed within 180 nmi of Pascagoula each year. The area is susceptible to storm surge, with water elevations of over 6 ft being recorded four times during the period of 1909 through 1969. One event on record resulted in a water elevation of 11.2 ft above mean sea level.

The hurricane season for Pascagoula is from late May through early November, with September being the major threat month. The principal threat is from tropical cyclones approaching from the southwest, south and southeast. When storms of record were at their closest point of approach (CPA) to Pascagoula, their average monthly direction of movement varied from 341° to 025°, with the overall average direction of movement being 005°.

Pascagoula is not a hurricane haven. Early threat assessment is essential. Limited evasion options dictate that sortie be initiated soon after Hurricane Condition III is set. Current plans call for the evacuation of all hands during hurricane threat, commencing with the setting of Hurricane Condition III. Evacuation rationale is based on the low elevation of Singing River Island and the Naval Station, susceptibility of the Mississippi Sound area to storm surge which could inundate the Naval Station as well as the causeway to/from the Naval Station, the absence of sheltered anchorages, narrow channels cut through shallow bay waters that would be vulnerable to blockage if a ship should sink during a storm, and the always present danger of damage from other vessels that may break loose from their moorings at the Port of Pascagoula, Ingalls Ship Yard or other locations near Pascagoula during strong winds.

Advice for shallow draft vessels is to remove them from the water and transport them to higher ground away from the Naval Station. If that is not feasible, limited shelter may be available in the upper reaches of the Pascagoula River or in Lake Yazoo.

This hurricane haven evaluation was prepared by D. Perryman, NRL Monterey CA and D. Gilmore and R. Englebretson of SAIC, Inc. Monterey CA.

1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

Naval Station Pascagoula, Mississippi is located on the mainland side of Mississippi Sound at approximately 30°20'N 88°35'W in the northeast portion of the Gulf of Mexico (Figure XXV-1). The Port of Pascagoula is an important deep water port in the Gulf region.

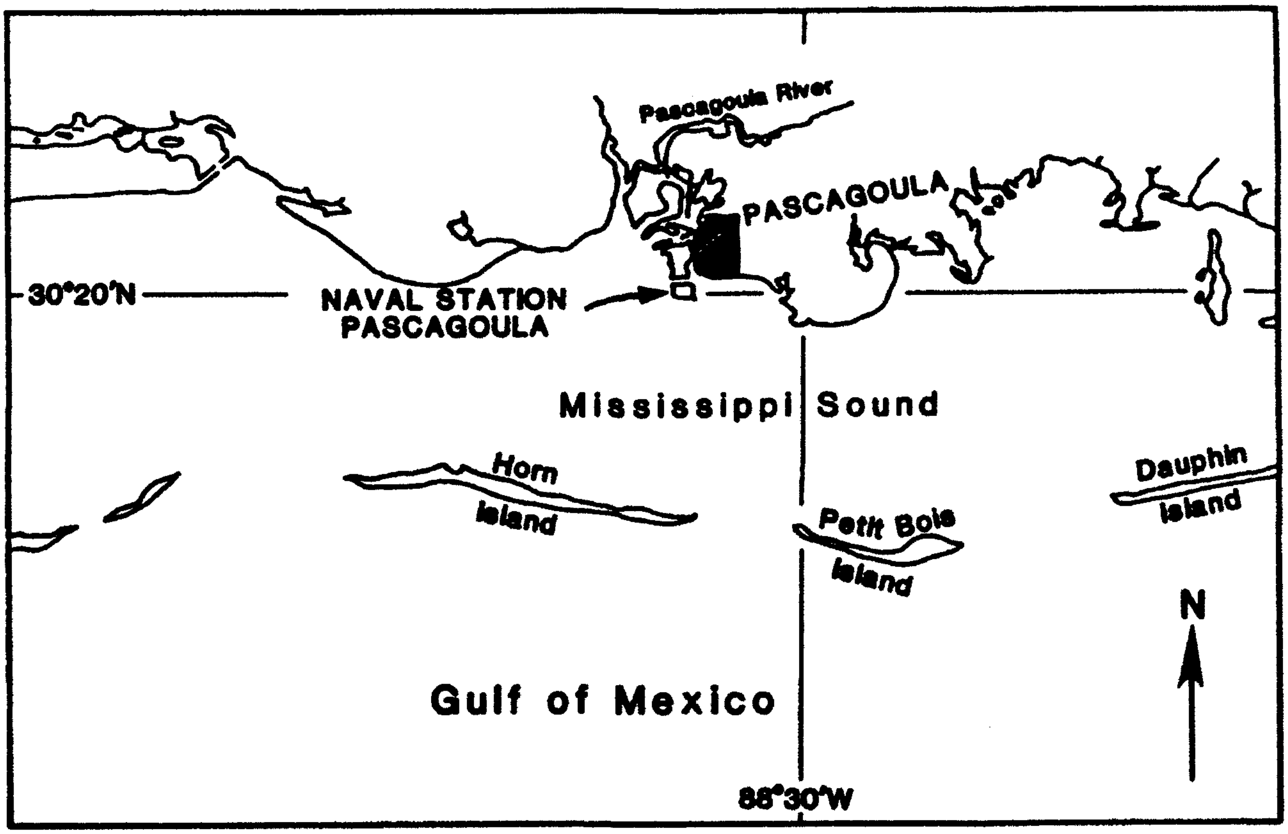

Figure XXV-1. Location of Pascagoula, MS on Mississippi Sound and the Gulf of Mexico.

Naval Station Pascagoula is located on the north side of small, man-made Singing River Island (Figure XXV-2). The island is situated just south of Ingalls Shipyard and southwest of the main port at Pascagoula. Access to the port from the open Gulf is gained via the Horn Island Pass Channel. The channel passes through dredged cuts between the extreme eastern limit of the water area between the east end of Horn Island and the western

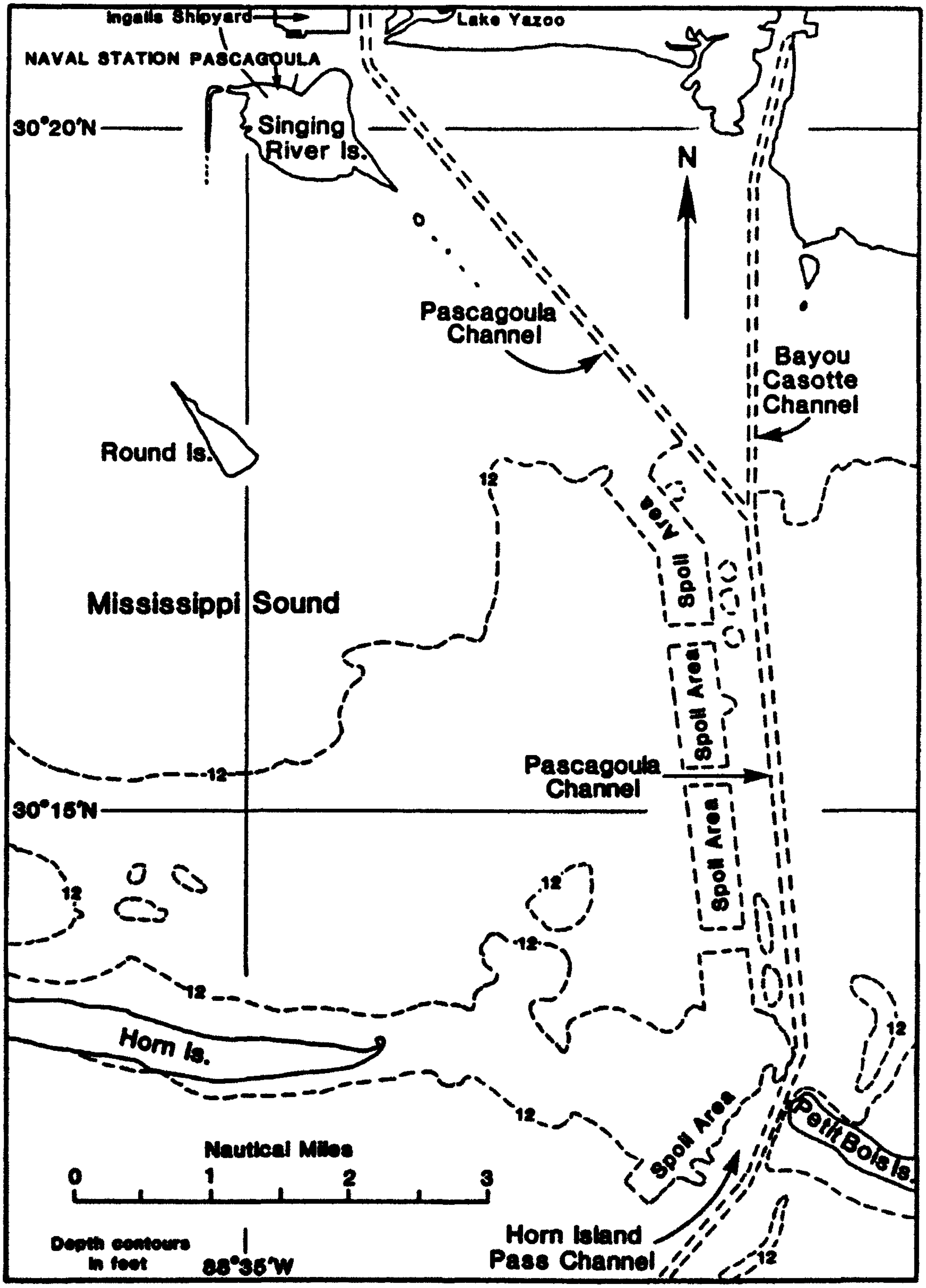

Figure XXV-2. Location of Singing River Island, Naval Station Pascagoula and Pascagoula Channel on Mississippi Sound.

end of Petit Bois Island. From there the 350-ft wide channel proceeds north and northwest, as Pascagoula Channel, about 9 nmi to Pascagoula and the Naval Station. The federal project depth of the channel is 40 ft in the Horn Island Pass Channel, and 38 ft in Mississippi Sound (U. S. Department of Commerce, 1980). However, Department of Commerce Chart 11373, 31st edition dated October 24, 1987 lists controlling depths from seaward in Pascagoula channel as 30 ft in the left outside quarter of the channel to 34.4 ft in the right outside quarter. Channel depth from the main ship channel to the Naval station is not specified. Outside the channel, Mississippi Sound is relatively shallow at the south end, ranging from 12 to 20 ft, and very shallow, as little as 2 to 4 ft, at the north end near Pascagoula.

The land on which the Naval Station is constructed is only about 2 or 3 ft above sea level. The surrounding terrain is also low in elevation. The only access to/from Singing River Island and the mainland is via a 14 ft high, 3-mile long causeway (Perryman and Picard, 1991). See Figure XXV-3.

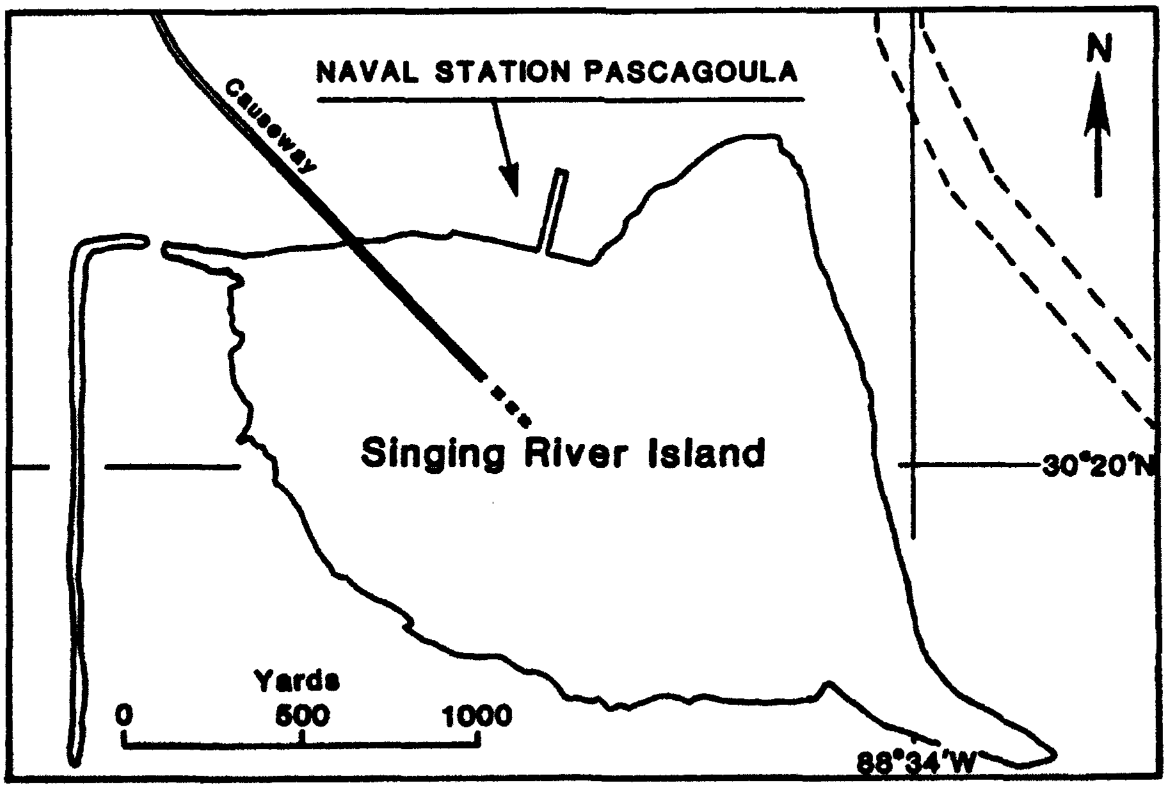

Figure XXV-3. Location of Naval Station Pascagoula on Singing River Island.

U. S. Coast Pilot 5, (1980) states that tides have a diurnal range of 1.7 ft at Horn Island Pass and 1.6 ft at the mouth of the Pascagoula River. The U.S. Department of Commerce chart 11375 lists extreme low water as -2.5 ft at Horn Island Pass and Pascagoula. Tidal currents in Horn Island Pass are reported to flood north and ebb south, averaging 1.2 kt at full flow. In the dredged cut the current follows the direction of the cut. The velocity and direction of the current, as well as the rise and fall of the tides, are greatly affected by the wind. Strong easterly winds and seas are reported to create strong currents along the shore.

2. PORT AND HARBOR FACILITIES

2.1 BERTHING FACILITIES FOR DEEP DRAFT VESSELS

The Naval Station has a single pier which extends north-northeastward from the north side of Singing River Island (Figure XXV-4). The pier, with a length of 680 ft, and a width of 80 ft, has two levels. Ship services are available from the lower level. Nesting will be required if more than two of the frigates assigned to Naval Station Pascagoula are in port at the same time. Additional moorage space for smaller vessels is provided at the quays along the shore at the south end of the pier.

2.2 ANCHORAGE

Weather permitting, deep draft vessels may anchor 1 to 2 miles south or southeast of the sea buoy (U. S. Department of Commerce, 1980). Anchorage for vessels with up to 15 ft draft is available in Mississippi Sound east of the channel.

2.3 AVAILABILITY OF OTHER HARBOR SERVICES

The Port of Pascagoula is equipped with extensive large and small ship repair facilities. Ingalls Shipbuilding Corporation has a floating drydock with a depth of 41 feet over the keel blocks, a lifting capacity of 38,000 tons, and can handle vessels up to 820 ft long and 170 ft wide. It also has a graving dock

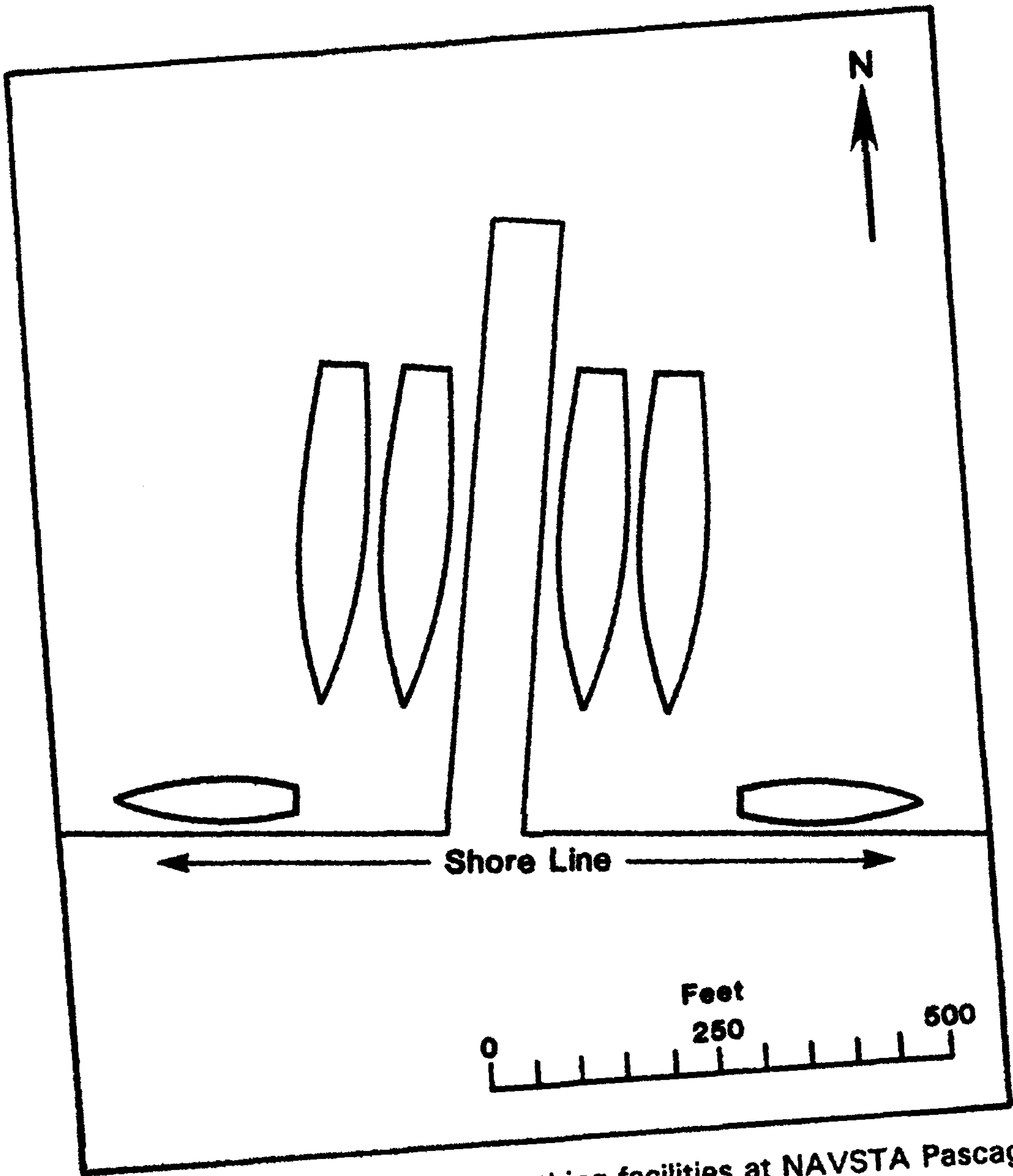

Figure XXV-4. Configuration of berthing facilities at NAVSTA Pascagoula.

485 ft long and 85 ft wide, with a depth of 35.8 ft over the keel blocks. Other facilities include cranes with up to 60-ton capacities at the outfitting piers, floating cranes with up to 50-ton capacities (U.S. Department of Commerce, 1980), and tugs with up to 4,200 hp.

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT PASCAGOULA

3.1 INTRODUCTION

By examining relevant characteristics of tropical cyclones such as track, speed of movement, intensity, month of occurrence, etc., some insight may be gained into their typical behavior. This background knowledge and understanding allows attention to be focused on those storms most likely to have a serious effect at Pascagoula. However, the historical behavior of storms and their impact should not be regarded as a reliable guide to the detailed behavior and impact of a particular storm as it approaches the port. Detailed attention should be paid to specific Navy and/or National Hurricane Center tropical cyclone warnings.

3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 nmi of Pascagoula is considered to represent a threat to the port. Table XXV-1 contains a descriptive history of all tropical storms and hurricanes passing within 180 nmi of Pascagoula during the 107-year period 1886-1992. All of the tropical cyclone statistics used in this report for storms passing within 180 nmi of Pascagoula are based on the SAIC-generated data set used to compile Table XXV-1. It should be noted that the wind values accompanied by an asterisk (*) in column 7 represent the maximum wind at CPA, and CPA may have occurred after the storm has moved on shore and weakened. The center winds were hurricane force (≥64 kt) at some time the storm was within 180 nmi and may have been that strong when the storm moved on shore. Hurricane Andrew, storm index number 105, is an example of such an event. It passed 164 nmi southwest of Pascagoula on a northwesterly track before moving on shore across Louisiana and Mississippi. Andrew subsequently had a CPA 128 nmi northwest of Pascagoula as it was moving northeast at 10.4 kt. As reflected in the table, Andrew's center winds were only 30 kt at CPA.

Table XXV-1. Descriptive history of all tropical storms and hurricanes passing within 180 nmi of Pascagoula during the period 1886-1992.

1 STORM INDEX NUMBER	2 STORM NAME	3 YEAR	4 MONTH	5 DAY	6 STORM NUMBER FOR YEAR	7 MAXIMUM WIND AT STORM CENTER	8 CPA (CLOSEST POINT OF APPROACH)	9 DDD/SS.S DDD=HEADING SS.S=FORWARD SPEED AT CPA
1	NOT NAMED	1886	JUN	15	1	35	165 (W)	062/ 9.9
2	NOT NAMED	1887	JUL	27	2	85	104 (ESE)	019/11.0
3	NOT NAMED	1887	OCT	19	11	45*	7 (SSE)	057/17.0
4	NOT NAMED	1888	AUG	20	3	77	172 (W)	348/ 8.2
5	NOT NAMED	1889	SEP	23	6	85	48 (SE)	055/17.1
6	NOT NAMED	1892	SEP	12	4	40	20 (NW)	035/18.2
7	NOT NAMED	1893	SEP	8	8	73	63 (WNW)	029/11.2
8	NOT NAMED	1893	OCT	2	10	73	4 (SSE)	042/11.2
9	NOT NAMED	1894	AUG	8	1	42	59 (ENE)	337/ 4.4
10	NOT NAMED	1894	OCT	8	4	98	179 (SE)	036/ 7.4
11	NOT NAMED	1895	AUG	16	1	40	0 (N)	016/ 5.8
12	NOT NAMED	1896	JUL	7	1	75	130 (E)	003/ 4.2
13	NOT NAMED	1897	SEP	12	2	78	139 (SSW)	292/13.3
14	NOT NAMED	1898	AUG	3	1	28	80 (NNE)	297/ 9.8
15	NOT NAMED	1900	SEP	13	3	35	2 (N)	030/ 4.8
16	NOT NAMED	1901	JUN	14	1	35	24 (ENE)	345/ 9.4
17	NOT NAMED	1901	AUG	15	4	45*	26 (WNW)	015/ 6.3
18	NOT NAMED	1901	SEP	17	6	41	72 (SE)	034/15.1
19	NOT NAMED	1902	OCT	10	4	48	27 (ESE)	036/13.4
20	NOT NAMED	1903	SEP	14	3	52*	140 (E)	350/ 6.1
21	NOT NAMED	1904	NOV	3	5	35	13 (SSE)	051/13.7
22	NOT NAMED	1905	SEP	30	3	35	133 (WNW)	027/12.8
23	NOT NAMED	1905	OCT	10	5	33	88 (WNW)	023/14.4
24	NOT NAMED	1906	JUN	13	1	39	155 (E)	357/11.0
25	NOT NAMED	1906	SEP	27	5	93	2 (W)	344/ 6.2
26	NOT NAMED	1907	JUN	28	1	49	144 (SSE)	056/11.9
27	NOT NAMED	1907	SEP	22	2	35	39 (NW)	040/11.3
28	NOT NAMED	1907	SEP	28	3	43	115 (SE)	052/23.1
29	NOT NAMED	1909	JUL	1	2	30	62 (NNE)	289/12.6
30	NOT NAMED	1909	SEP	20	7	75	115 (WSW)	345/14.7
31	NOT NAMED	1911	AUG	12	1	60*	31 (NE)	319/ 6.6
32	NOT NAMED	1912	JUN	13	1	36	52 (NNW)	060/20.2
33	NOT NAMED	1912	SEP	14	3	63*	8 (ESE)	345/14.4
34	NOT NAMED	1914	SEP	18	1	35	28 (S)	261/12.4
35	NOT NAMED	1915	SEP	4	4	72	166 (E)	002/16.1
36	NOT NAMED	1915	SEP	30	5	60*	66 (W)	015/12.2
37	NOT NAMED	1916	JUL	6	1	100	24 (WSW)	331/ 9.7
38	NOT NAMED	1916	OCT	18	13	91	72 (E)	011/20.4
39	NOT NAMED	1917	SEP	28	3	100	79 (SE)	053/ 9.9
40	NOT NAMED	1919	JUL	4	1	36	73 (ENE)	341/ 6.2
41	NOT NAMED	1920	SEP	22	2	82	143 (WSW)	339/16.2
42	NOT NAMED	1922	OCT	17	3	33	34 (ENE)	327/ 4.8
43	NOT NAMED	1923	OCT	16	3	57*	140 (W)	350/20.3
44	NOT NAMED	1923	OCT	18	6	40	22 (WSW)	356/23.6
45	NOT NAMED	1924	SEP	15	4	68	123 (SE)	046/ 7.2
46	NOT NAMED	1926	AUG	26	3	65	148 (W)	349/ 5.9
47	NOT NAMED	1926	SEP	21	6	60*	22 (S)	279/ 6.1
48	NOT NAMED	1928	AUG	15	2	39	168 (ENE)	345/11.1
49	NOT NAMED	1929	SEP	30	2	55	176 (ESE)	012/ 5.2
50	NOT NAMED	1931	JUL	15	2	36	149 (WSW)	344/ 8.5
51	NOT NAMED	1932	SEP	1	3	65	4 (ENE)	324/ 8.7
52	NOT NAMED	1932	SEP	14	5	45	159 (SSE)	074/18.3
53	NOT NAMED	1932	SEP	20	6	34	147 (WNW)	019/31.2
54	NOT NAMED	1932	OCT	16	8	38	33 (NW)	045/14.4
55	NOT NAMED	1934	JUN	16	2	62*	124 (W)	360/11.0

NOTES:
Datetimes are in UTC, winds are in knots, distances are in nautical miles. Parenthetical expression in column 8 gives bearing of storm from site at closest point of approach to site (CPA). Maximum winds are at time of CPA and did not necessarily occur at site. Asterisk (if any) after maximum wind indicates that storm was classified as a hurricane (at least 64 kts) somewhere within 180 nautical mile radius of site but not at CPA. Site location is 30.7°N, 88.6°W.

Table XXV-1. Continued. Descriptive history of all tropical storms and hurricanes passing within 180 nmi of Pascagoula during the period 1886-1992.

1 STORM INDEX NUMBER	2 STORM NAME	3 YEAR	4 MONTH	5 DAY	6 STORM NUMBER FOR YEAR	7 MAXIMUM WIND AT STORM CENTER	8 CPA (CLOSEST POINT OF APPROACH)	9 DDD/SS.S DDD=HEADING SS.S=FORWARD SPEED AT CPA
56	NOT NAMED	1934	JUL	24	3	39	155 (S)	266/12.4
57	NOT NAMED	1934	OCT	6	9	35	31 (ESE)	023/ 6.5
58	NOT NAMED	1936	JUL	27	4	33	53 (WNW)	016/31.9
59	NOT NAMED	1936	AUG	1	5	33*	76 (ENE)	326/ 6.1
60	NOT NAMED	1937	SEP	20	6	40	96 (SSE)	072/13.5
61	NOT NAMED	1937	OCT	4	9	26	152 (WNW)	030/12.0
62	NOT NAMED	1939	JUN	16	1	33	22 (ENE)	332/12.6
63	NOT NAMED	1939	AUG	14	2	25*	74 (NE)	324/ 2.8
64	NOT NAMED	1939	SEP	26	3	30	103 (WSW)	028/ 6.5
65	NOT NAMED	1940	AUG	5	2	58*	173 (S)	279/ 6.3
66	NOT NAMED	1941	SEP	12	1	35	161 (S)	272/ 3.5
67	NOT NAMED	1943	JUL	25	1	60*	158 (S)	274/14.2
68	NOT NAMED	1944	SEP	10	6	32	21 (NW)	031/17.8
69	NOT NAMED	1946	JUN	14	1	35	120 (S)	271/ 9.7
70	NOT NAMED	1947	SEP	19	4	99	65 (SW)	299/20.4
71	NOT NAMED	1947	SEP	8	5	31	14 (WSW)	309/11.1
72	NOT NAMED	1948	JUL	8	2	35	108 (SE)	049/13.8
73	NOT NAMED	1948	SEP	4	5	51*	56 (WNW)	014/12.5
74	NOT NAMED	1949	SEP	4	5	40	109 (WNW)	014/10.2
75	BAKER	1950	AUG	31	2	65	42 (E)	001/14.2
76	ALICE	1953	JUN	6	1	35	148 (E)	360/ 2.7
77	NOT NAMED	1953	SEP	19	7	60	130 (SSE)	065/ 8.9
78	FLORENCE	1953	SEP	26	8	78	110 (ESE)	027/ 9.5
79	BRENDA	1955	AUG	1	1	53	67 (SW)	318/10.7
80	NOT NAMED	1955	AUG	27	5	40	52 (SSW)	294/13.2
81	NOT NAMED	1956	JUN	14	1	40	98 (W)	358/16.4
82	FLOSSY	1956	SEP	24	7	80	62 (SSE)	064/11.6
83	DEBBIE	1957	SEP	8	5	35	102 (ESE)	028/11.9
84	ESTHER	1957	SEP	18	6	42	98 (W)	360/11.0
85	IRENE	1959	OCT	8	10	47	59 (ESE)	023/10.5
86	ETHEL	1960	SEP	16	6	45*	21 (W)	360/ 7.0
87	HILDA	1964	OCT	4	10	55*	4 (SE)	094/13.0
88	NOT NAMED	1965	JUN	15	1	45	106 (SE)	046/20.4
89	BETSY	1965	SEP	10	3	120	124 (SW)	315/18.5
90	DEBBIE	1965	SEP	30	5	30	45 (SSW)	341/ 5.3
91	CAMILLE	1969	AUG	18	3	116	49 (WSW)	342/13.7
92	SUBTROP	1969	OCT	1	12	26	109 (E)	359/15.0
93	EDITH	1971	SEP	17	6	37*	92 (NNW)	056/ 9.2
94	AGNES	1972	JUN	19	2	65	168 (ESE)	017/ 9.7
95	CARMEN	1974	SEP	8	6	113	159 (SW)	328/ 8.2
96	ELOISE	1975	SEP	23	5	110	123 (ESE)	017/24.3
97	BABE	1977	SEP	6	2	28*	69 (NW)	039/ 7.9
98	BOB	1979	JUL	11	2	40*	84 (WNW)	010/17.3
99	FREDERIC	1979	SEP	13	6	95	8 (NE)	342/12.9
100	ELENA	1985	SEP	2	5	100	32 (SSW)	298/14.9
101	JUAN	1985	OCT	31	10	56*	51 (SE)	042/16.1
102	KATE	1985	NOV	21	11	85	158 (SE)	032/11.5
103	BERYL	1988	AUG	8	2	34	73 (SW)	109/ 2.3
104	FLORENCE	1988	SEP	10	7	55*	81 (SW)	322/13.3
105	ANDREW	1992	AUG	27	1	30*	128 (NW)	045/10.4

NOTES:
Datetimes are in UTC, winds are in knots, distances are in nautical miles. Parenthetical expression in column 8 gives bearing of storm from site at closest point of approach to site (CPA). Maximum winds are at time of CPA and did not necessarily occur at site. Asterisk (if any) after maximum wind indicates that storm was classified as a hurricane (at least 64 kts) somewhere within 180 nautical mile radius of site but not at CPA. Site location is 30.7°N, 88.6°W.

The gulf coast near Pascagoula is located on the north shore of the Gulf of Mexico and is oriented perpendicular to normal cyclone tracks as they move more or less northward out of the tropics. The region's position between 25 and 30 degrees north latitude places it within the normal locus of tropical cyclone recurvature. The locus oscillates between latitudes 25°N and 35°N during the tropical cyclone season. This factor is significant since it is the character of tropical cyclones to slow and intensify during the recurvature stage. This is the most difficult phase of the tropical cyclone life cycle to actually forecast. Factors of difficulty include the rate of recurvature, the storm speed of movement subsequent to recurvature, and consequently, the storm's precise future position at a specific point in time.

The hurricane season along the Gulf Coast is late May through early November. During the 107-year period from 1886 to 1992 there were 105 tropical storms and hurricanes that met the 180 nmi threat criterion for Pascagoula, an average of about 1 per year. Figure XXV-5 shows the monthly distribution of the 105 storms. It is obvious that the month of greatest tropical cyclone threat to Pascagoula is September.

Figure XXV-6 depicts the yearly distribution of tropical storms and hurricanes passing within 180 nmi of Pascagoula. During 40 years of the 107-year history there have been no occurrences of tropical cyclones passing within 180 nmi of Pascagoula. This includes 10 of the last 13 years of the record (1980-1992).

Table XXV-2 shows the monthly frequency and motion history of the 105 tropical storms and hurricanes which passed within 180 nmi of Pascagoula during the period 1886-1992. The average movement for the storms at the closest point of approach (CPA) is 005 degrees at 12 kt. Approximately 2 of every 7 tropical cyclones passing within 180 nmi of Pascagoula are of at least minimum hurricane strength.

Figure XXV-7 presents a graphical depiction of the number of tropical cyclones versus CPA. The storm classification is based on the maximum wind near the storm center while that center was within 180 nmi of Pascagoula, not necessarily at CPA.

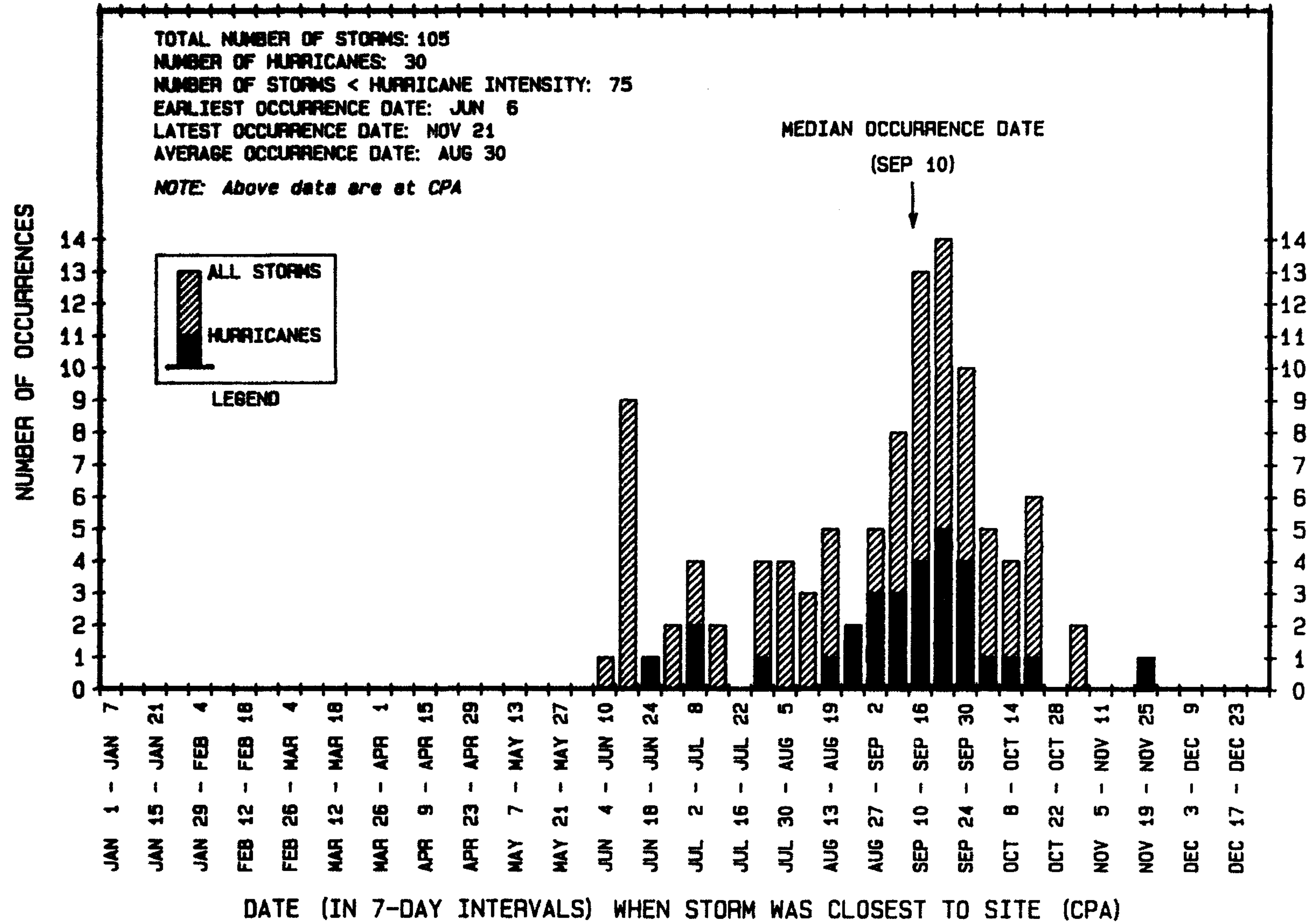

Figure XXV-5. Monthly distribution of all tropical storms and hurricanes passing within 180 nmi of Pascagoula during the 107 year period 1886-1992.

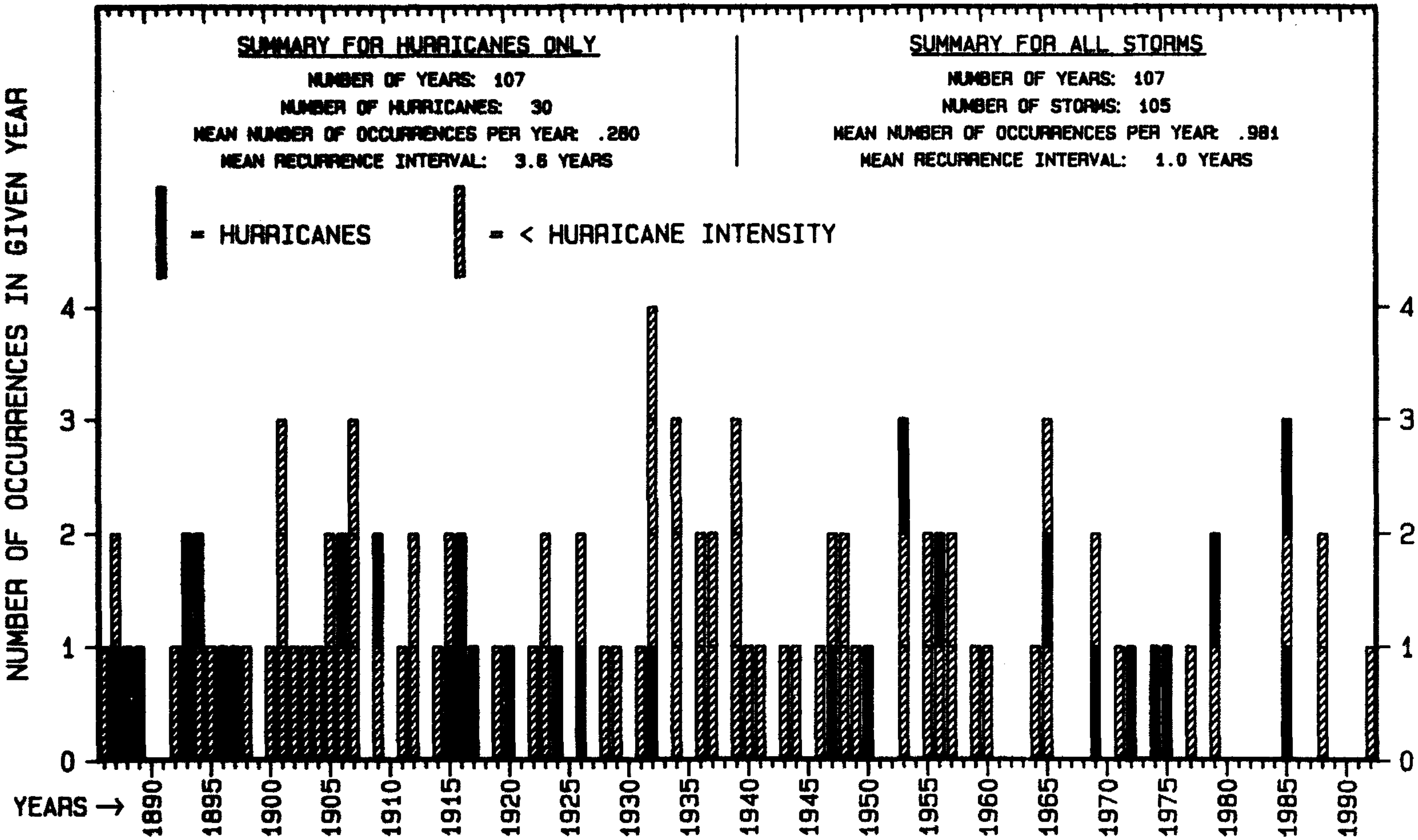

Figure XXV-6. Chronology of all tropical storms and hurricanes passing within 180 nmi of Pascagoula during the 107 year period 1886-1992. Storm intensity is determined at time of closest point of approach (CPA) to Pascagoula.

Table XXV-2. Frequency and motion of tropical storms and hurricanes passing within 180 nmi of Pascagoula over the 107 year period 1886-1992.

Total number of storms passing within 180 n mi	0	0	0	0	0	13	10	17	47	16	2	0	105
Number of storms having at least hurricane intensity at CPA	0	0	0	0	0	1	3	4	18	3	1	0	30
Number of storms less than hurricane intensity at CPA	0	0	0	0	0	12	7	13	29	13	1	0	75
Average heading (degs) towards which storms were moving at CPA	---	---	---	---	---	006	348	341	007	025	*	---	005
Average storm speed (knots) at CPA	---	---	---	---	---	12	13	8	12	13	*	---	12
Month when storm was at CPA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR

** indicates insufficient storms for average direction and speed computations.*

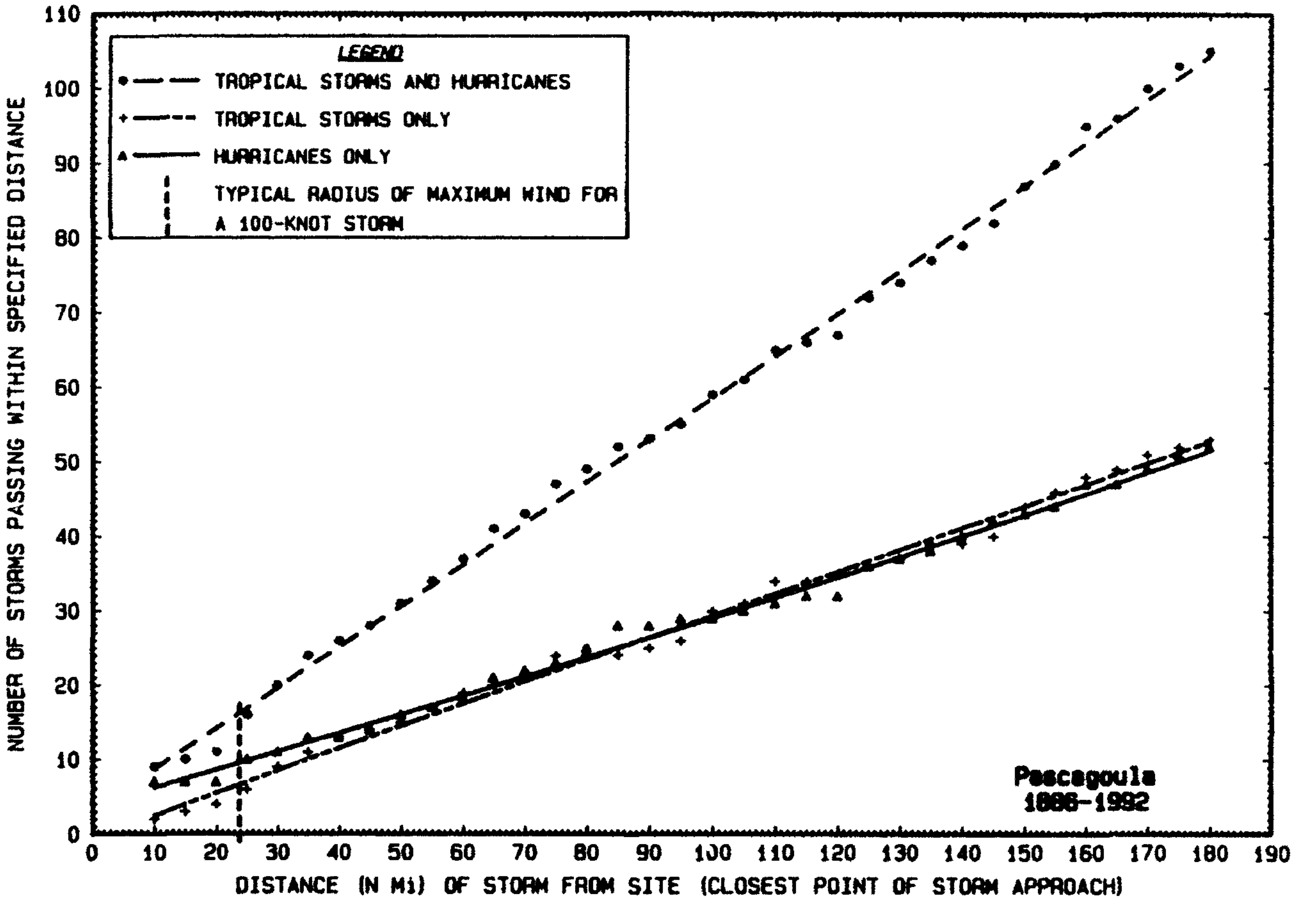

Figure XXV-7. Number of tropical cyclones passing at various distances from Pascagoula over the 107 year period of record. Tropical storm or hurricane classification is based on maximum wind near storm center while that center was within 180 nmi of site, and not necessarily at CPA. Sloping lines represent mathematical fit to data points. Average radius of maximum wind for 34, 100 and 140 kt storms at Pascagoula are 25.3, 23.7, and 29.8 respectively.

Figure XXV-8 displays the storms as a function of the compass octant from which they approached Pascagoula. It is evident that the major threat is from tropical cyclones approaching from the south and southwest. It should be noted, however, that the approach direction is determined at CPA and may not represent the initial approach direction of the tropical cyclone toward Pascagoula.

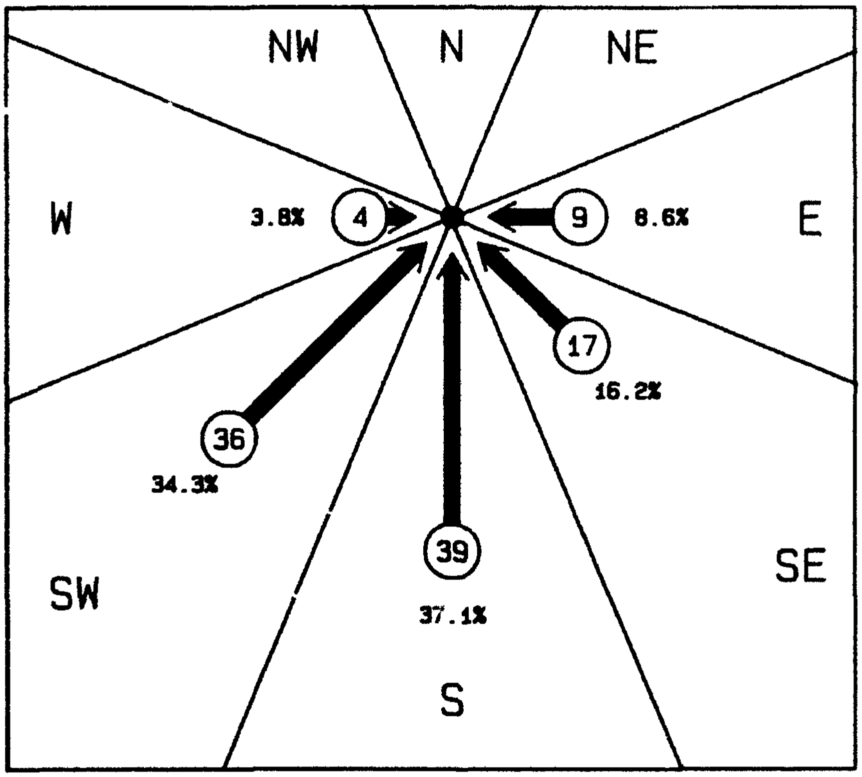

Figure XXV-8. Directions of approach for 105 tropical cyclones passing within 180 nmi of Pascagoula during the 107 year period of record. Length of directional arrow is proportional to the number of storms given in the circles of each octant. Approach directions are determined at CPA.

Figures XXV-9 through XXV-12 provide information on the probability of remote tropical cyclones passing within 180 nmi of Pascagoula and the average time to CPA. A comparison of the figures shows some distinct differences in threat axis according to time of year. The least active period, November through June, shows the major threat axis to be from nearly due south, then extending south-southeastward to the western Caribbean Sea through the Yucatan Channel. The threat axis for the July and August period is significantly different in that it has two lobes, the primary lobe extending southeastward through the Straits of Florida before progressing eastward to the subtropical North Atlantic Ocean between 23°N and 25°N latitude and the second extending south-southeastward through the Yucatan Channel into the Caribbean Sea. By September the major axis has shifted southward through the Yucatan Channel into the Caribbean Sea and eastward north of South America along about 15°N. The October threat axis has shifted to the Gulf of Campeche west of the Yucatan Peninsula, indicating that the greatest threat is from recurving storms entering the Gulf of Mexico from the Caribbean Sea or from storms originating or passing through the Gulf of Campeche. Two storms of record initially formed in the Pacific Ocean south of Mexico and crossed the rather narrow portion of Mexico near the Gulf of Tehuantepec into the Gulf of Campeche before moving northward across the Gulf of Mexico.

3.3 ENVIRONMENTAL EFFECTS

3.3.1 WIND AND TOPOGRAPHY

The relatively low-lying topography surrounding Naval Station Pascagoula affords little protection; it is exposed to the full effects of tropical cyclone winds. History has shown that the region is susceptible to strong winds and associated weather phenomena.

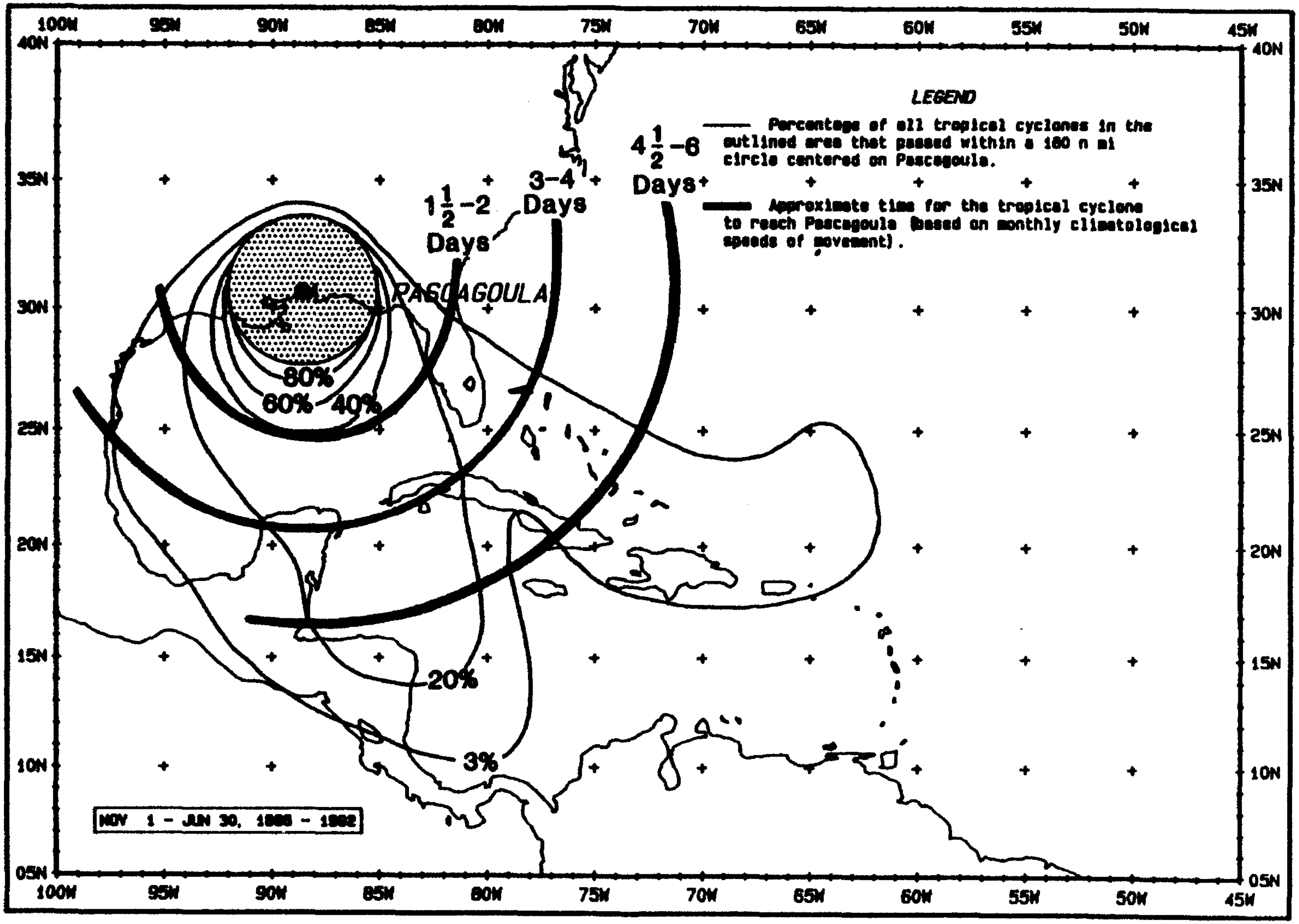

Figure XXV-9. Probability that a tropical storm or hurricane will pass within 180 nmi of Pascagoula (circle), and approximate time to closest point of approach, during the period November through June (based on data from 1886-1992).

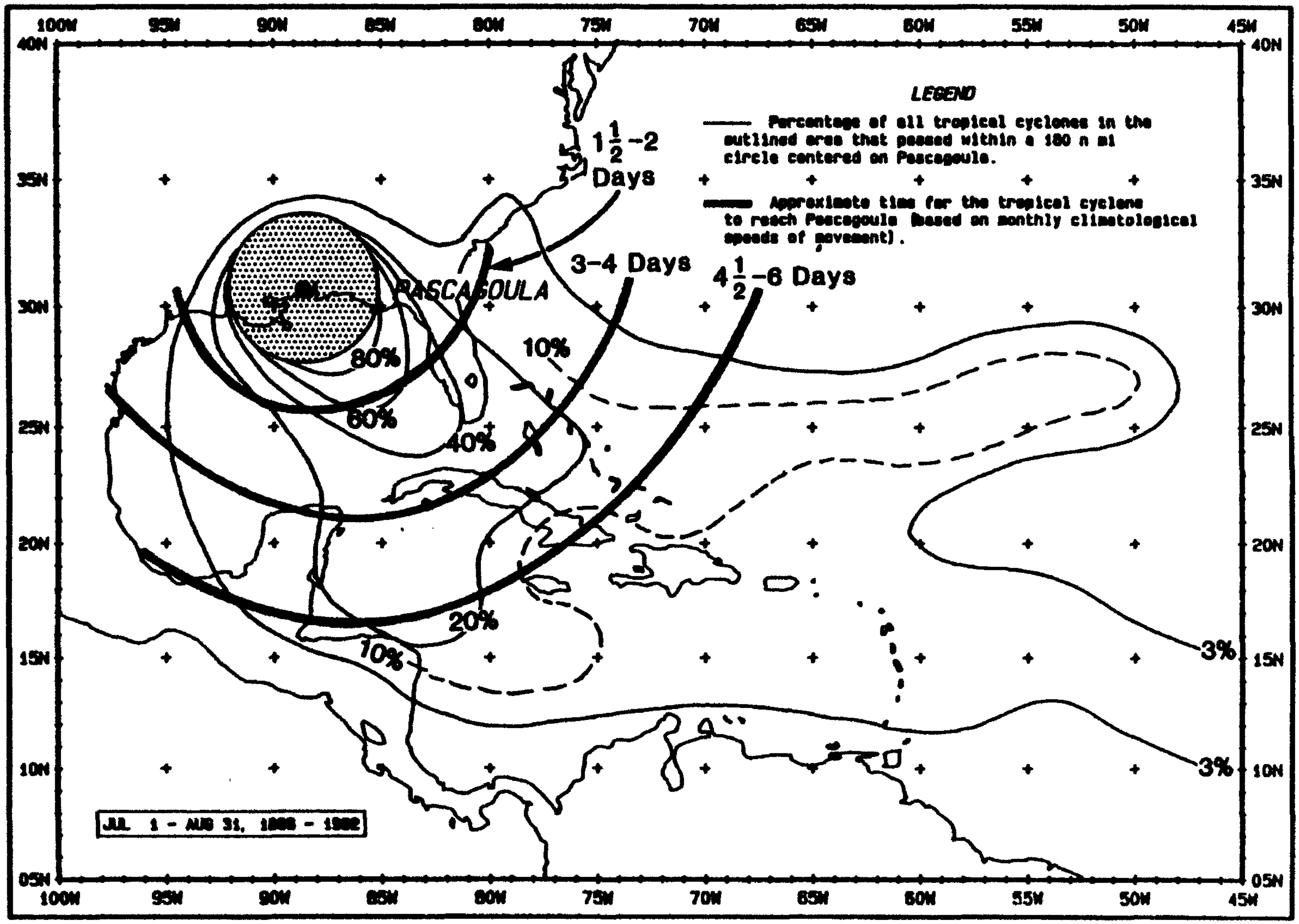

Figure XXV-10. Probability that a tropical storm or hurricane will pass within 180 nmi of Pascagoula (circle), and approximate time to closest point of approach, during July and August (based on data from 1886-1992).

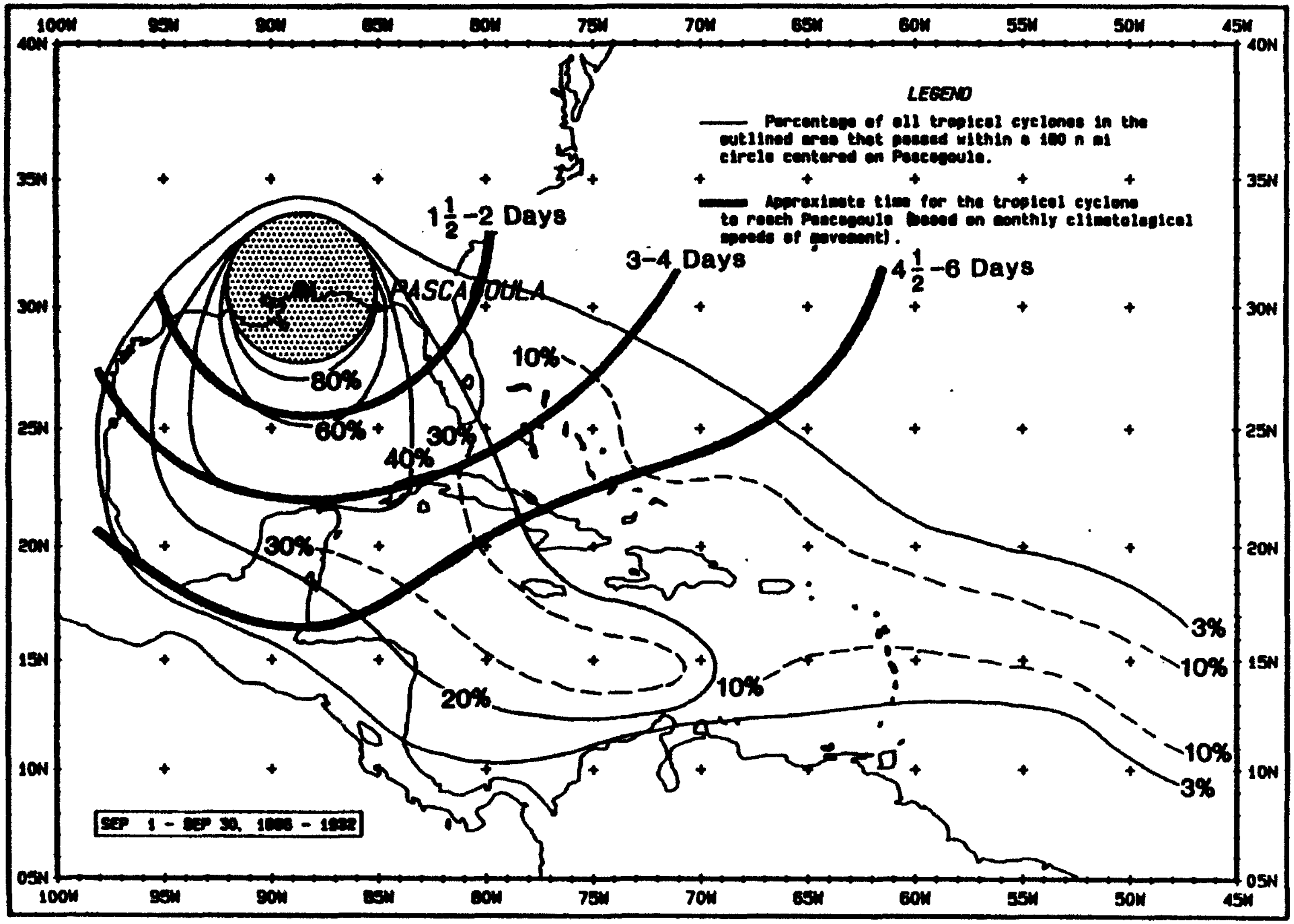

Figure XXV-11. Probability that a tropical storm or hurricane will pass within 180 nmi of Pascagoula (circle), and approximate time to closest point of approach, during September (based on data from 1886-1992).

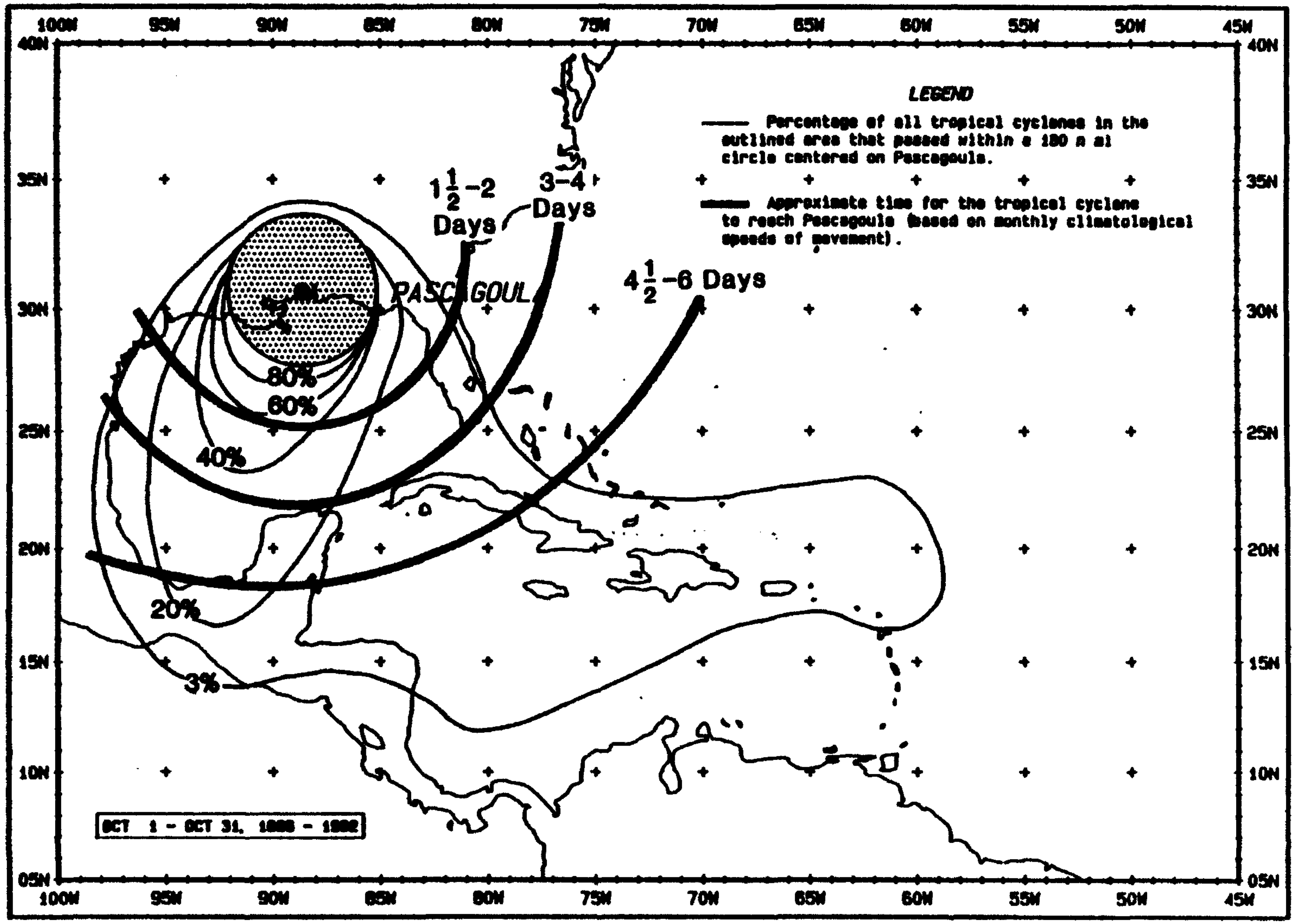

Figure XXV-12. Probability that a tropical storm or hurricane will pass within 180 nmi of Pascagoula (circle), and approximate time to closest point of approach, during October (based on data from 1886-1992).

3.3.2 STORM SURGE AND TIDES

Although wind damage from a tropical cyclone can be severe, storm surge may pose a greater threat to life and property in the low lying coastal areas. Storm surge may be visualized as a raised dome of water, moving with the storm, and centered a few miles to the right of its path. The dome height is related to local pressure (i.e., a barometric effect dependent on the intensity of the storm) and to local winds. Other significant contributing factors are storm speed, direction of approach, bottom topography, and coincidence with astronomical tide.

The worst combination of circumstances (Harris, 1963, and Pore and Barrientos, 1976) would include:

(1) An intense storm approaching perpendicular to the coast with the harbor within 30 nmi to the right of the storm's track.

(2) Broad, shallow, slowly shoaling bathymetry.

(3) Coincidence with high astronomical tide.

The waters of the Gulf coast near Pascagoula meet the bathymetry criteria. This factor, coupled with the fact that Mississippi Sound is large, relatively shallow over most of its extent, has a rather large entrance open to seaward, and the barrier islands along its southern limit are very low in elevation renders Pascagoula vulnerable to storm surges.

Research in storm surge prediction techniques has led to the development of am advanced storm surge forecasting tool. Developed by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service, it is known by its acronym "SLOSH", which stands for Sea, Lake, and Overland Surges from Hurricanes (Jelesnianski and Chen, 1979). The Tri-state Hurricane Evacuation Study, Mississippi, Alabama, and Florida contains charts which detail the storm surge levels for the states listed. It also lists historical hurricane tide elevations for Pascagoula as shown in Table XXV-3.

Table XXV-3. Historical record of hurricane tide elevations at Pascagoula, Mississippi.

DATE	HEIGHT ABOVE MEAN SEA LEVEL
SEPTEMBER 20, 1909	8 to 12 FT
SEPTEMBER 19, 1947	7.7 FT
SEPTEMBER 10, 1965	6.4 FT
AUGUST 18, 1969	11.2 FT

In addition to the foregoing, U. S. Coast Pilot 5 (1980) states, "*During hurricane Camille in August 1969, the Ingalls Shipbuilding Corporation recorded a peak gust of 181 mph, while storm tides in the area rose to 11.2 feet above mean sea level. During Frederic in September 1979, Pascagoula was battered by gusts to 127 mph, 11 inches of rain, and 6-foot storm tides.*" The SLOSH model calculates storm surge values for five storm intensities, each corresponding to a category on the "Saffir/Simpson Scale". This scale, shown in Table XXV-4, was developed by Herbert Saffir and Dr. Robert H. Simpson.

Table XXV-4. Saffir/Simpson scale.

	CENTRAL PRESSURE		WIND		
SCALE NO.	MB	INCHES	MPH	KNOTS	DAMAGE
1	>980	>28.94	74-95	64-83	Minimal
2	965-979	28.50-28.91	96-110	84-95	Moderate
3	945-964	27.91-28.47	111-130	96-113	Extensive
4	920-944	27.17-27.88	131-155	114-135	Extreme
5	<920	<27.17	155+	135+	Catastrophic

Figures XXV-13 through XXV-17 show the extent of storm surge intrusion on the land area adjacent to Naval Station Pascagoula for hurricane categories 1 through 5, and have been adapted from

Appendix A of Tri-state Hurricane Evacuation Study, Mississippi, Alabama and Florida, published by the Department of the Army in 1986. In addition, interstate highway 10, which runs east-west just north of Pascagoula, is thought to act as a dam so water can build up south of it, causing water levels to exceed SLOSH model expectations (Perryman and Picard, 1991). Since the station is built on land with elevations only 2 to 3 ft above sea level, it is not surprising to see that Singing River Island would even be completely inundated by the storm surge associated with a Category 1 storm, the weakest of the five categories.

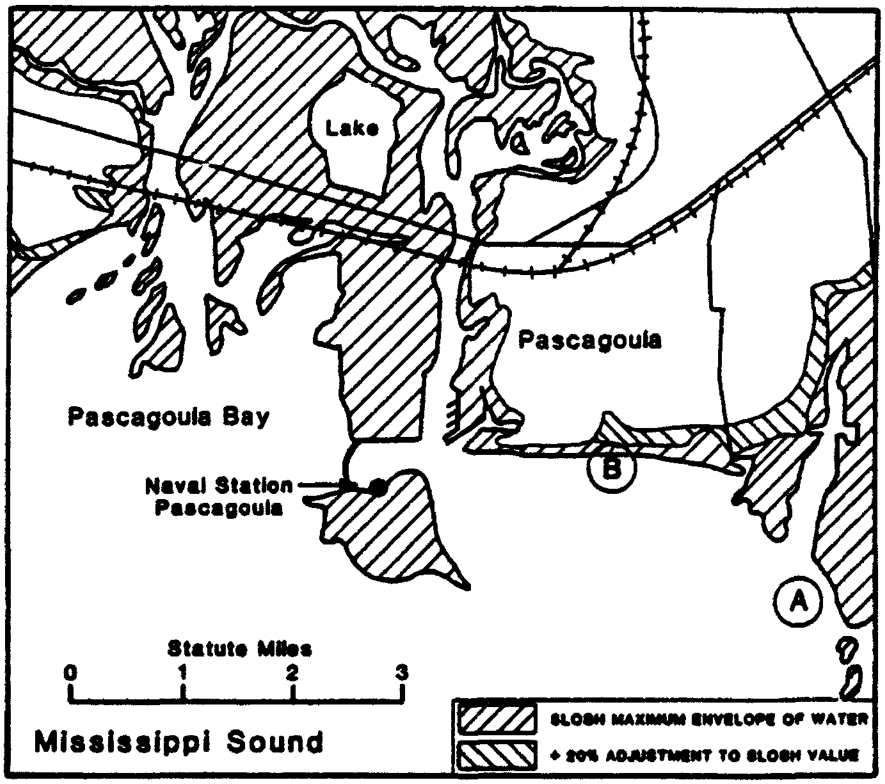

Figure XXV-13. Category 1 storm surge contours. Adapted from Tri-state Hurricane Evacuation Study, Mississippi, Alabama, Florida dated June '86; as are Figures XXV-14,15,16, & 17.

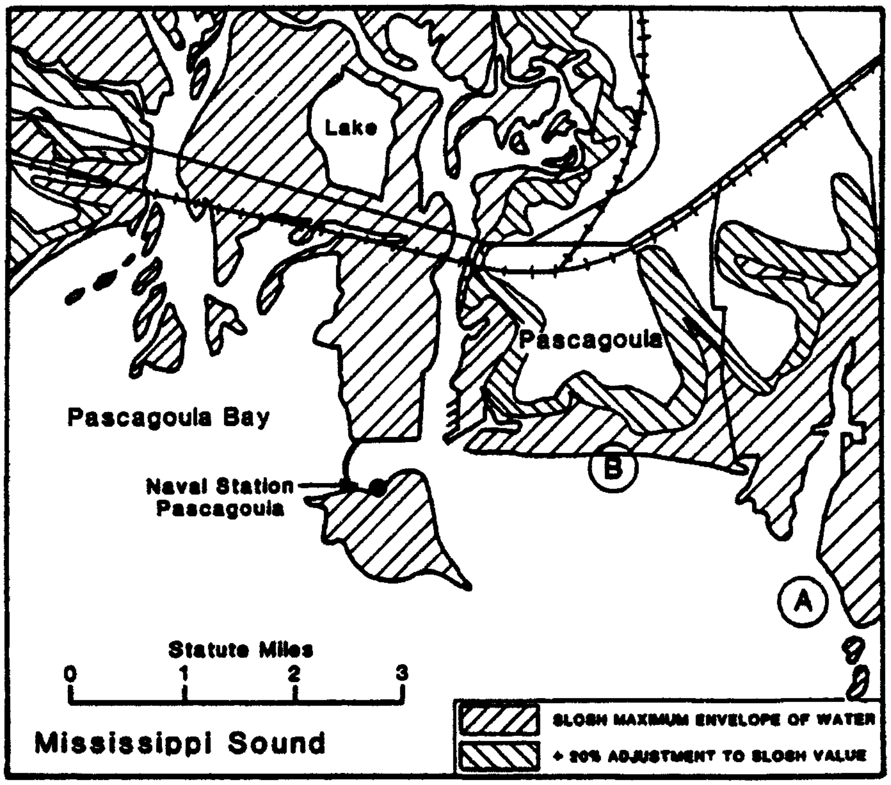

Figure XXV-14. Category 2 storm surge contours.

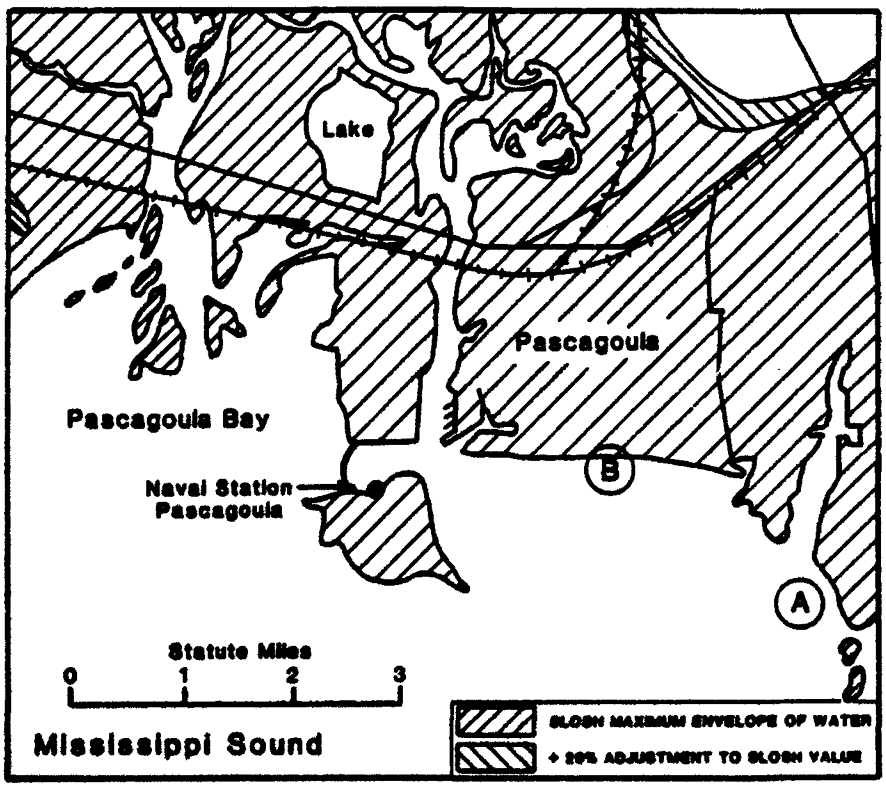

Figure XXV-15. Category 3 storm surge contours.

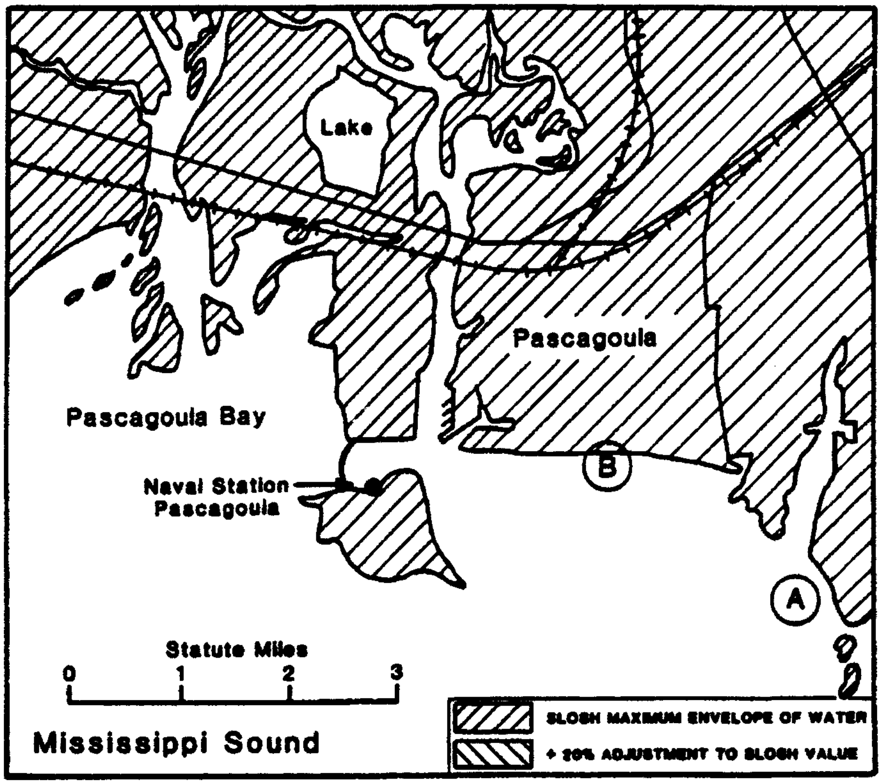

Figure XXV-16. Category 4 storm surge contours.

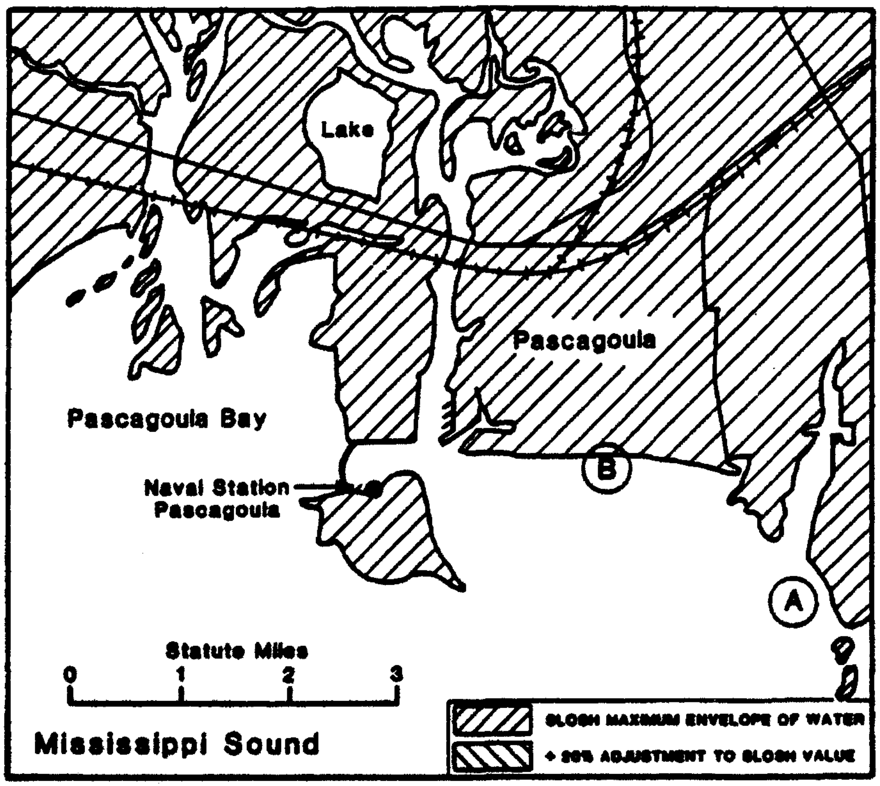

Figure XXV-17. Category 5 storm surge contours.

Figures XXV-13 through XXV-17 only show the extent of storm surge intrusion; the anticipated surge heights are not provided. While no forecast heights are available for the exact location of Naval Station Pascagoula, the Tri-state Hurricane Evacuation Study, Mississippi, Alabama and Florida indicates the storm surge heights listed in Table XXV-5 are to be expected at the locations indicated by the letters "A" and "B" in Figures XXV-13 through XXV-17.

Table XXV-5. Storm surge heights for the location indicated by the letters "A" and "B" in Figures XXV-13 through XXV-17. Adapted from Department of the Army (1986).

	SURGE HEIGHT IN FEET ABOVE M.S.L.		ADJUSTED SURGE HEIGHT IN FEET ABOVE M.S.L. (See note below)	
STORM CATEGORY	A	B	A	B
1	5.6	5.7	6.5	6.6
2	9.4	9.4	11.1	11.1
3	13.3	13.5	15.7	16.0
4	16.3	16.6	19.3	19.7
5	17.5	18.6	20.8	22.1

NOTE: Adjusted surge heights represent a 20% increase in calculated SLOSH surge height values.

It is significant to note that any of the forecast storm surge heights given in Table XXV-5 would inundate the Naval Station, and the adjusted surge heights for storm categories 3 through 5 would cover the 14 ft high causeway leading to/from the Naval Station.

4. THE DECISION TO EVADE OR REMAIN IN PORT

At the time of the port visit (Perryman and Picard, 1991), the base was not yet commissioned, but significant progress in disaster preparedness was being made by the Port Operations Officer. A destructive weather plan has been placed into effect by NAVSTA Pascagoula and SIMA Pascagoula. Plans call for the evacuation of all hands during any hurricane, starting with Hurricane Condition II. Naval Station Pascagoula is within Commander Naval Base Charleston's Sub-region "C", and is covered by Chief of Naval Education and Training (CNET) Instruction 3140.1, Subject: DESTRUCTIVE WEATHER BILL FOR COMNAVBASE CHARLESTON SUB-REGION "C".

4.1 THREAT ASSESSMENT

The tropical cyclone threat analysis presented in Section 3 of this evaluation indicates that the Pascagoula area is at considerable risk from both storm surge and high wind. The absence of significant protection from high wind and storm surge, and the lack of protected anchorages make evasion at sea the safest course of action for all seaworthy, deep-draft vessels. Evasion should be initiated as soon as it is established that a particular tropical cyclone poses a threat to Pascagoula. Early assessment of each potential threat is essential. Assessment should be related to the setting of hurricane conditions of readiness by military and civil authorities, based on current advisories and forecasts issued by the Navy and National Weather Service, as well as climatology.

The Chief of Naval Education and Training (CNET), Naval Air Station, Pensacola, Florida is the Sub-Regional Planning Agent (SRPA) for COMNAVBASE Charleston's Sub-region "C", in which Naval Station Pascagoula is located. As SRPA, CNET is responsible for setting Hurricane and Tropical Storm Conditions of Readiness for individual warning areas located in Sub-Region "C." Pascagoula is situated in warning area C-2. Additionally, by direction, the Naval Oceanography Command Detachment (NAVOCEANCOMDET), Pensacola issues destructive weather warnings, as listed in CNET Instruction 3140.1, for activities in Sub-Region "C".

Individual storm intensity and speed of movement will affect the potential for damage which can be expected from any given storm. As a general rule, any intense tropical storm or hurricane approaching from the Gulf of Mexico such that Pascagoula is located in the dangerous right front quadrant of the storm can result in severe wind and storm surge conditions.

The pier at Naval Station Pascagoula extends north-northeastward from the shore of Singing River Island and would afford little protection to ships moored on either side.

The biggest problem will be flooding. The maximum storm surge generated by the SLOSH model for the port area is 20.8 ft with a Category 5 storm (Table XXV-5), but there is flooding indicated at the base under <u>all</u> categories due to its low elevation.

4.2 EVASION AT SEA

NAVSTA Pascagoula Destructive Weather Plan Appendix IX sets forth guidelines for action taken with regard to the port operations pier and ships. Appendix IX also plans for the movement of small craft to safe locations. Evasion at sea is the recommended course of action for all seaworthy deep draft vessels when Pascagoula is under threat from a strong tropical cyclone. Timing of the decision to evade is affected by:

(1) The forward speed of the tropical cyclone.
(2) The radius of hazardous winds and seas that can impact on a vessel's ability to reach open water and then maneuver to evade.
(3) The elapsed time to make preparations to get underway.
(4) The elapsed time to reach open water.

For example:

The worst potential problem would be a hurricane moving directly toward Pascagoula from the south. The frigates based at the Naval Station are gas turbine powered, and have minimal cold iron problems, but still require a few hours to get underway. If 6 hours are required to make preparations for sortie after the decision to evade at sea is made, and another hour is required to transit to open sea (about 9 nmi at 9-10 kt), a hurricane approaching at 10 kts will be 70 nmi closer to Pascagoula by the time open water is reached. When the radius of strong winds likely to hamper operations, about 200 nmi, is added, it gives 270 nmi (or 27 hours) as the minimum hurricane displacement from Pascagoula when the sortie must be initiated in order to avoid heavy weather (Picard, 1992). A greater margin may be applicable depending on an increased storm speed of advance, a greater radius of strong winds, if there is increased ship preparation time, or increased transit time in the Pascagoula Channel.

Hurricane Condition III is set when hurricane force (≥ 64 kt) winds are possible within 48 hours. It is apparent that the decision to sortie should be made soon after the time Hurricane Condition III is set. Although at this time the storm center may be more than 500 nmi distant, it should be remembered that the average 48-hour forecast error is greater than 200 nmi. The storm center may be much nearer (or farther) from Pascagoula or significantly left or right of its forecast track than the 48-hour forecast indicates. A departure soon after Hurricane Condition III is set is suggested as the wisest and safest course of action. Later departures wager the accuracy of information on the storm's behavior against mounting risks of heavy weather damage.

Once sea room is attained, the tactics employed will depend on the location of the threatening tropical cyclone, its speed of advance, and its direction of movement. Up-to-date information is essential if sound decisions are to be made. Tropical cyclone location and intensity information based on today's satellite technology is accurate and timely. Forecasts and warnings are issued at 6-hourly intervals and updated as necessary to reflect important changes in position, intensity, and movement. Ship masters with access to these advisories/warnings are in the best possible position to modify evasion routes and tactics to successfully evade the storm.

A cardinal rule of seamanship is to avoid the dangerous right-hand semicircle of a hurricane, but due to the limited evasion options, the rule may have only limited application in the Gulf of Mexico. A storm approaching from the southwest effectively limits the evasion options to a course to the southeast quadrant. Since there are no other options, the ship is placed in the potentially more dangerous right-hand semicircle.

The following guidelines are offered.

(1) Tropical cyclone approaching from east or southeast: Steam southwest to increase distance from storm, taking advantage of northerly (following) winds and seas. However, Pascagoula's proximity to and location east of the Mississippi River delta dictates that about 40 nmi must be travelled once the Gulf of Mexico is reached before open water to the southwest is attained. This factor makes an early departure even more critical to avoid getting trapped between the approaching storm and the delta.

(2) Tropical cyclone approaching from west or southwest: Sortie early to avoid head winds and seas and steam southeast. This option may place the ship in the dangerous right hand semicircle of the storm, but an early departure will allow sufficient time to evade the storm before it reaches the ship.

(3) Tropical cyclone approaching from south: WORST CASE! Evasion tactics must be based on the latest forecast position and movement. While precautions must be taken to avoid the strong winds of the storm's right semicircle, limited directional options may offer little choice other than taking a course that enters the dangerous semicircle. If such a course is taken, it must be started early and pursued with all deliberate speed in order to avoid strong winds. Early departure is necessary if heavy weather is to be avoided. Delaying departure for any reason will seriously restrict evasion options and may make remaining in port the safest tactic. Be alert for storm recurvature to the northeast!

4.3 RETURNING TO PORT

The damage and disarray at a port resulting from a tropical cyclone strike may include navigation hazards such as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Erosion and restructuring of barrier islands and channels is extremely likely in the Gulf coast area of Pascagoula. Due caution should be exercised following tropical cyclone passage. Naval Station services may be so damaged as to preclude offering even minimal services.

4.4 REMAINING IN PORT

Little protection from wind is available at Naval Station Pascagoula, and no protection from storm surge exists. If a vessel cannot get underway due to mechanical problems, it should be ballasted down as much as possible, and secured to the doc with sufficient mooring lines, including spring lines, to withstand predicted wind forces, yet allow water height fluctuations of the predicted amounts.

In August 1992, hurricane Andrew passed 164 nmi southwest of Pascagoula on a west-northwesterly course that ultimately took the storm south of the Mississippi Delta and into southwestern Louisiana. USS Gallery was at Naval Station Pascagoula and unable to sortie, but it survived the storm. One report states that the ship was taking water over the main deck and needed more lines to hold it to the pier, but another stated that extra lines had been added and the ship was never in distress. All personnel at the Naval Station were evacuated so no one was left to monitor the situation during the strongest winds. One shortcoming was brought to light during Andrew's passage; there were no direct communications between Naval Oceanography Command Detachment, Pensacola, which issues destructive weather warnings for CNET, and any of the frigates homeported at Pascagoula.

If the decision is made to remain in port it should be borne in mind that the vessel will be exposed to dangers beyond that of wind and storm surge. Vessels in other portions of the Port of Pascagoula may break loose from their moorings and become floating hazards. Also, there is a danger that a damaged or sunken vessel could effectively block the narrow ship channels and trap shipping at the pier for some time after a storm has passed.

4.5 ADVICE TO SHALLOW DRAFT VESSELS

Since the Naval Station is constructed on land which is only 2 to 3 ft above sea level, the usual precaution of removing the small craft from the water and securing them at least 20 ft above sea level to avoid possible high water does not apply. However, the Destructive Weather Plan instructs the Port Operations Officer to relocate all waterborne small craft to safe harbor and all trailerable small craft to safe enclosed storage. The plans outlined in Appendix IX call for the movement of small craft upriver to safe harbor. Likely locations for safe harbor would include the upper reaches of the Pascagoula River, which has several marinas, service wharves, and boat yards near Pascagoula. There is a municipal boat basin with berths for small craft up to 40 ft at the head of Lake Yazoo (Figure XXV-2). In 1983 a reported depth of 5-1/2 ft could be carried to the basin. Additionally, a facility at Paige Bayou has been utilized in the past and offers good protection for small craft.

If a river location is selected, the following extract from U. S. Coast Pilot 5 (U. S. Department of Commerce, 1980) is relevant:

> *"Hurricane moorings. On receiving advisory notice of a tropical disturbance small boats should seek shelter in a small winding stream whose banks are lined with trees, preferably cedar or mangrove. Moor with bow and stern lines fastened to the lower branches; if possible snug up with good chafing gear. The knees of the trees will act as fenders and the branches, having more give than the trunks, will ease the shocks of the heavy gusts. If the banks are lined only with small trees or large shrubs, use clumps of them within each hawser loop. Keep clear of any tall pines as they generally have shallow roots and are more apt to be blown down."*

Using open water anchorages to ride out the passage of a tropical cyclone is extremely hazardous. Virtually no protection is afforded except near lee shores. Wind wave activity can be quite destructive, not to mention the hazards of floating debris resulting from the effects of wind waves, high water, and high winds.

The prudent small boat operator will have selected several potential havens beforehand in which to take shelter in various tropical cyclone threat situations. He will proceed to his haven well in advance to avoid the chaos and congestion endured by his fellow boaters who delay until the onset of destructive conditions is imminent.

REFERENCES

Chief of Naval Education and Training (CNET) Instruction 3140.1(series), Subject: Destructive Weather Bill for COMNAVBASE Charleston Sub-region "C". Issued by Chief of Naval Education and Training, Naval Air Station, Pensacola, Florida 32506-5100

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U. S. Department of Commerce, 1980: United States Coast Pilot 5, Atlantic Coast: Gulf of Mexico, Puerto Rico, and Virgin Islands. National Oceanic and Atmospheric Administration, National Ocean Survey, Washington, DC.

PORT VISIT INFORMATION

November 1991. NRL Meteorologists Dennis Perryman and Roland Picard met with LT Jim Pluth, Port Operations Officer of Naval Station Pascagoula and Mr. Hank Turk, Jackson County Disaster Preparedness Office, to obtain a portion of the information contained in this report.

XXVI. NS INGLESIDE, TEXAS

SUMMARY

Tropical cyclones pose a significant threat to Naval Station Ingleside. During the 107-year period 1886-1992, an average of 0.8 tropical storms or hurricanes passed within an 180 nmi radius of Ingleside each year. Several of the storms produced sustained winds in excess of 40 kt with gusts of over 70 kt. Hurricane Celia brought sustained winds of 95 kt with gusts to 140 kt. The Corpus Christi Bay area is susceptible to storm surge. The potential exists for water elevations to exceed 7 ft during storms of only moderate strength, and 10-12 ft under specific storm strength and track scenarios. The Naval Station is constructed above all predicted surge levels.

The hurricane season is from late May through early November, with August and September being the months of greatest activity at Ingleside. Storms approaching from the southeast pose the greatest threat to Ingleside. The average movement for all storms at their closest point of approach (CPA) is 319° at 10 kts.

Although Naval Station Ingleside can hardly be considered a good hurricane haven, limited evasion options greatly reduce the options for a sortie to be completed without encountering heavy weather. NAVSTAINGLE-SIDEINST 3730.1 states that sortie is NOT the recommended course of action when Ingleside is directly threatened with destructive force winds or an inundating severe storm surge from a tropical cyclone. The rationale given for the recommendation is based on several factors, including the geographical location and coastal orientation of the Gulf of Mexico, and the limited evasion speed of Mine Warfare ships homeported at Ingleside. If sortie is chosen, it should be initiated by SOPA as soon as it can be established that a particular tropical cyclone poses a threat to Ingleside, and no later than 48 hours prior to the onset of gale force (≥34 kt) winds, or approximately coincident with the setting of Hurricane Condition III.

Advice for small craft is to remove them from the water and secure above forecast water levels. None of the small channels and canals used by small boats in the Corpus Christi Bay area offers sufficient protection from the effects of a strong tropical cyclone passage.

This hurricane haven evaluation was prepared by D. Perryman, NRL Monterey CA and R. Gilmore and R. Englebretson of SAIC, Inc. Monterey CA.

1. **GEOGRAPHIC LOCATION AND TOPOGRAPHY**

Ingleside, Texas is located near 27°49'N 97°12'W on the north side of Corpus Christi Bay, on the south Texas coast of the Gulf of Mexico (Figure XXVI-1).

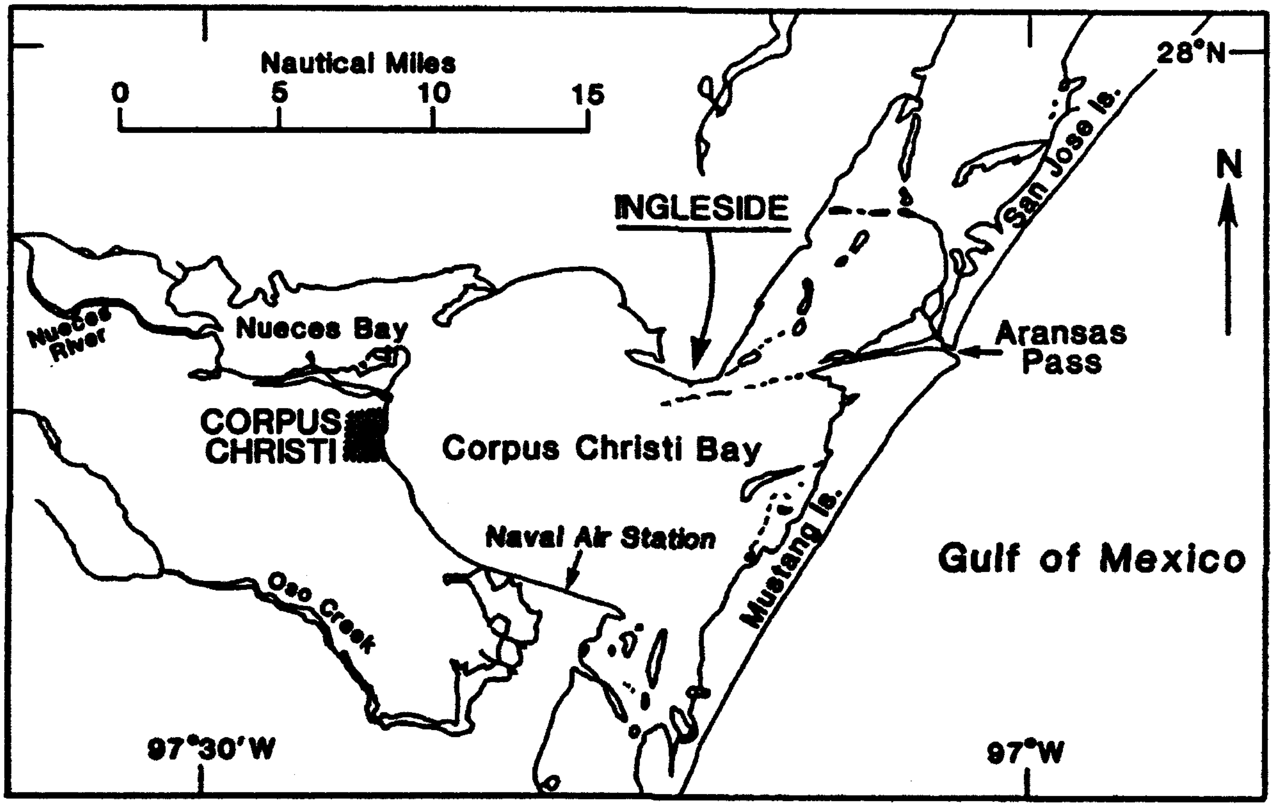

FIGURE XXVI-1. Location of Ingleside, Texas on Corpus Christi Bay and Gulf of Mexico.

Naval Station Ingleside is situated adjacent to Corpus Christi Channel on the north side of Corpus Christi Bay, about 8.5 nmi west of the open waters of the Gulf of Mexico (Figure XXVI-2). Corpus Christi Channel is entered through Aransas Pass, which passes between San Jose and Mustang Islands. With its entrance protected by jetties, the channel has project depths of 45 to 47 feet in the outer bar channel, and 45 feet in the jetty channel and westward to Corpus Christi (U. S. Department of

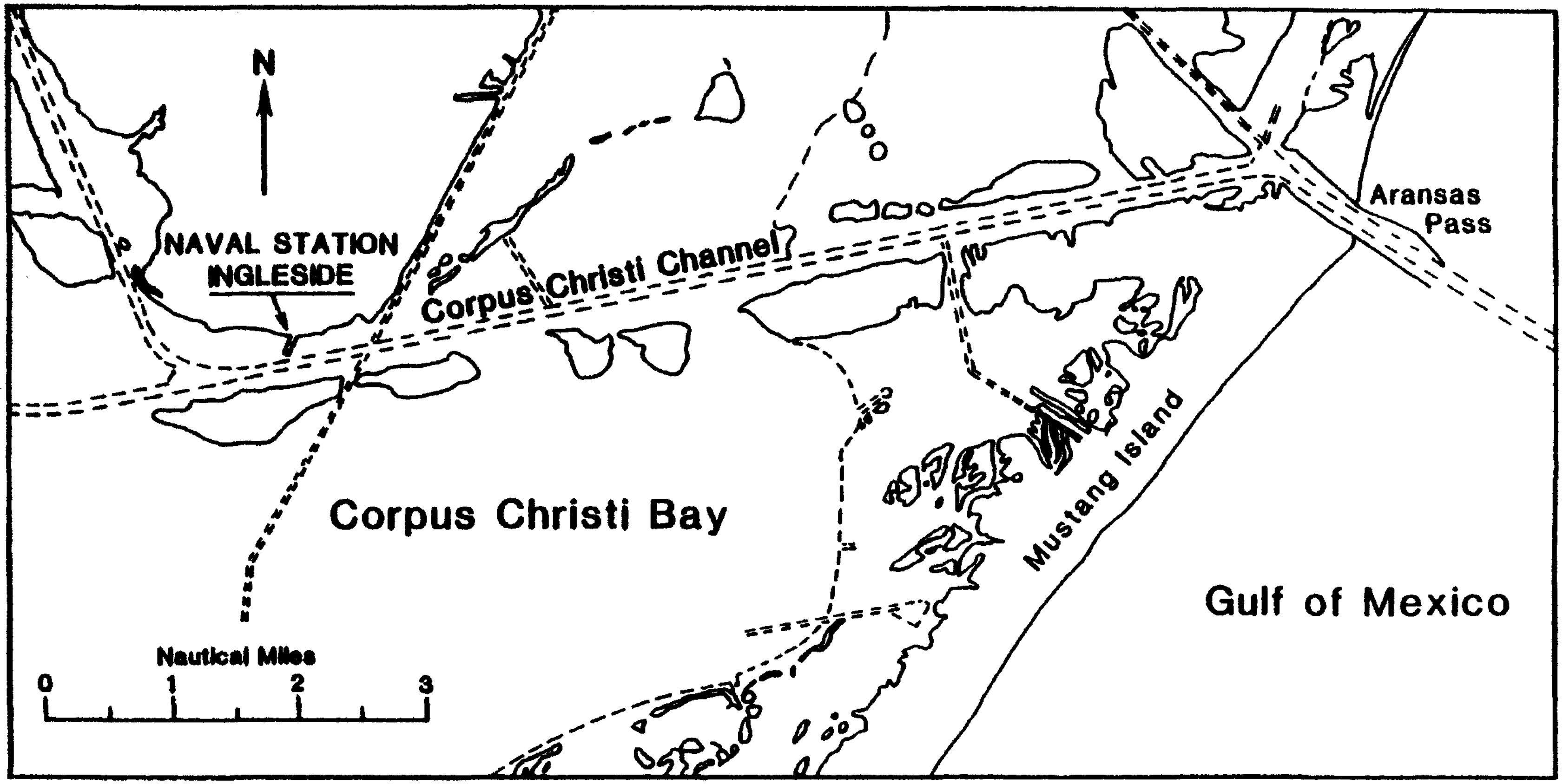

Figure XXVI-2. Location of Naval Station Ingleside adjacent to Corpus Christi Channel on Corpus Christi Bay.

Commerce, 1980). The channel leading from Aransas Pass to the Naval Station is somewhat protected by adjacent, low lying islands for most of its extent. Outside the channel, the water near Naval Station Ingleside is relatively shallow, with depths less than 5 ft not uncommon.

According to U. S. Coast Pilot (1980), tides are diurnal, with a range of 1.4 feet at Aransas Pass. The periodic tide in Corpus Christi Bay is reported to be too small to be of any practical importance. Currents in Aransas Pass have velocities exceeding 2.5 kts at times, and are greatly influenced by the wind. Outside Aransas Pass, currents are variable, but when reinforced by northerly winds, south-setting currents have been reported as high as 4 kts across the mouth of the jetties. Any wind with a strong easterly component will create rough conditions across the bar at the channel entrance, and may raise water levels inside the bar by as much as 2 ft. Westerly winds have an opposite effect on water levels inside the bar. Additionally, a sudden shift of the wind from south to north causes an "especially rough bar" for a short time.

2. PORT AND HARBOR FACILITIES

2.1 BERTHING FACILITIES FOR DEEP DRAFT VESSELS

Naval Station Ingleside was originally constructed to accommodate a Battle Group composed of a battleship, a large aircraft carrier, and several smaller vessels. These plans led to the construction of an 1,100-ft pier, with additional berthing space provided along 2 quay walls (Figure XXVI-3). Changes in fleet structure have altered the plans so that Ingleside is now home port to 3 frigates and 22 minesweepers instead of the Battle Group.

The 1100 foot pier is 23.5 feet above mean tide level. The east and west quay walls are 13.5 feet above mean water. Project depth of the east basin is 45 feet; west basin 35 feet.

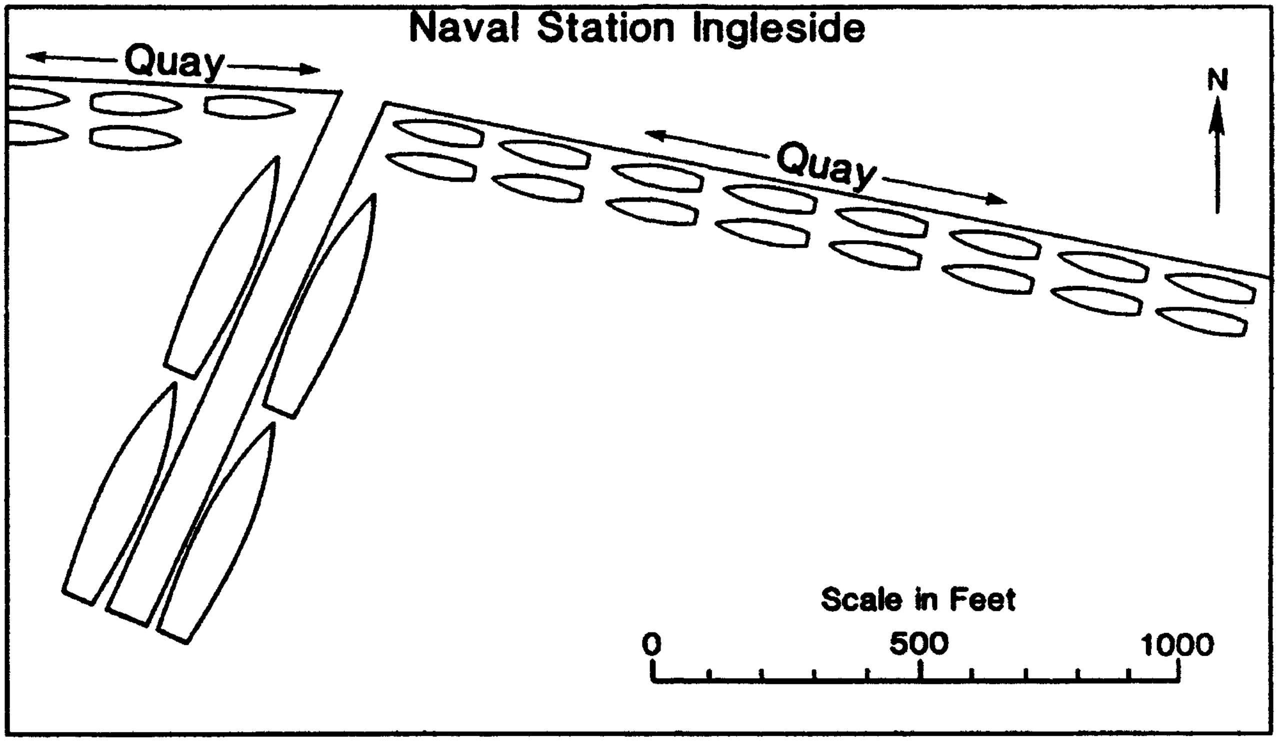

Figure XXVI-3. Configuration of berthing facilities at NS Ingleside.

2.2 ANCHORAGE

According to U. S. Coast Pilot 5 (1980), vessels should anchor off Aransas Pass in the Aransas Pass Fairway Anchorages. There is no suitable anchorage for deep-draft vessels inside Aransas Pass. Shallow-draft vessels of up to 10-ft draft can anchor about 1 nmi inside Aransas Pass in an area just north of Inner Basin. Other anchorages for shallow-draft vessels can be found in Corpus Christi Bay in depths of 13 to 15 ft.

2.3 AVAILABILITY OF OTHER HARBOR SERVICES

Tugs up to 4,000 hp are available at Corpus Christi and serve all of the Corpus Christi Bay area (U. S. Department of Commerce, 1980). The Port of Corpus Christi has mobile cranes to 600 tons, a 45-ton floating crane, and one 100-ton stiff-legged derrick.

Corpus Christi has no facilities for making major repairs or for dry-docking deep-draft vessels. The nearest such facilities are at Galveston, Texas, but repair facilities are available for medium-draft vessels. The largest floating drydock has a lifting capacity of 2,200 tons, with a length of 200 ft, width of 70 ft, and has 16 ft over the keel blocks. The largest vertical boat lift has a capacity of 170 tons and can handle 125 ft vessels. A marine railway with a cradle length of 140 ft and a clear width of 52 ft at the top of the keel blocks can handle keeled vessels up to 650 tons and flat bottom craft to 1,000 tons. Several well equipped firms are available for making above-the-waterline repairs to vessels.

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT INGLESIDE

3.1 INTRODUCTION

By examining relevant characteristics of tropical cyclones such as track, speed of movement, intensity, month of occurrence, etc., some insight of their typical behavior may be gained. This background knowledge and understanding provides focus on those storms most likely to have a serious effect on Ingleside. However, the historical behavior of storms and their impact should not be regarded as the most reliable guide to the behavior and impact of a particular storm as it approaches the port. But rather, one should pay detailed attention to situation specific Navy and/or National Hurricane Center tropical cyclone warnings.

3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 nmi of Ingleside is considered to represent a threat to the port. Table XXVI-1 shows a descriptive history of all tropical storms and hurricanes passing within 180 nmi of Ingleside during the 107-year period 1886-1992. All tropical cyclone statistics used in this report for storms passing within 180 nmi of Ingleside are based on the SAIC-generated data set shown in Table XXVI-1. It should be noted that the center

Table XXVI-1. Descriptive history of all tropical storms and hurricanes passing within 180 nmi of Ingleside during the period 1886-1992.

1 STORM INDEX NUMBER	2 STORM NAME	3 YEAR	4 MONTH	5 DAY	6 STORM NUMBER FOR YEAR	7 MAXIMUM WIND AT STORM CENTER	8 CPA (CLOSEST POINT OF APPROACH)	9 DDD/SS.S DDD=HEADING SS.S=FORWARD SPEED AT CPA
1	NOT NAMED	1886	JUN	14	1	48	86 (ESE)	018/10.7
2	NOT NAMED	1886	AUG	20	5	130	29 (NNE)	308/11.3
3	NOT NAMED	1886	SEP	24	7	75	16 (W)	006/ 7.0
4	NOT NAMED	1887	SEP	21	7	85	112 (S)	262/ 7.3
5	NOT NAMED	1888	JUN	17	1	75	95 (NE)	319/ 4.0
6	NOT NAMED	1888	JUL	5	2	50	95 (ENE)	347/ 7.2
7	NOT NAMED	1891	JUL	5	1	85	84 (E)	002/10.0
8	NOT NAMED	1895	AUG	29	2	35*	79 (SSW)	303/ 8.3
9	NOT NAMED	1895	OCT	6	4	47	81 (ESE)	024/19.4
10	NOT NAMED	1898	SEP	27	6	50	122 (E)	360/ 6.6
11	NOT NAMED	1900	SEP	9	1	82	148 (NE)	312/13.8
12	NOT NAMED	1901	JUL	10	2	36	74 (NE)	312/15.2
13	NOT NAMED	1902	JUN	26	2	80	11 (E)	001/ 9.0
14	NOT NAMED	1908	SEP	18	5	48	178 (E)	352/ 4.1
15	NOT NAMED	1909	JUN	30	1	37	52 (S)	281/ 7.1
16	NOT NAMED	1909	JUL	22	3	42*	105 (NNE)	280/12.6
17	NOT NAMED	1909	AUG	28	5	60*	137 (SSW)	291/10.7
18	NOT NAMED	1910	AUG	31	1	33	165 (SSW)	290/ 8.7
19	NOT NAMED	1910	SEP	14	2	65	60 (S)	279/ 9.5
20	NOT NAMED	1912	OCT	17	5	60*	34 (WSW)	329/ 7.0
21	NOT NAMED	1913	JUN	28	1	62*	41 (SSW)	303/12.8
22	NOT NAMED	1915	AUG	17	2	78	131 (NE)	307/11.9
23	NOT NAMED	1916	AUG	18	4	80	58 (SSW)	302/16.9
24	NOT NAMED	1919	SEP	14	2	95	35 (SSW)	287/10.3
25	NOT NAMED	1921	JUN	22	1	99	53 (E)	357/11.0
26	NOT NAMED	1922	JUN	16	1	32	137 (WSW)	329/30.6
27	NOT NAMED	1925	SEP	7	1	35	84 (SW)	310/11.7
28	NOT NAMED	1929	JUN	28	1	78	44 (NE)	303/12.7
29	NOT NAMED	1931	JUN	28	1	35	38 (SW)	312/ 6.0
30	NOT NAMED	1932	AUG	14	2	125	146 (NE)	324/ 8.8
31	NOT NAMED	1932	OCT	15	8	45	165 (ESE)	029/18.4
32	NOT NAMED	1933	JUL	23	4	40	86 (ENE)	339/ 9.7
33	NOT NAMED	1933	AUG	4	5	83	115 (SSE)	246/ 9.0
34	NOT NAMED	1933	SEP	5	11	120	98 (S)	264/ 8.2
35	NOT NAMED	1934	JUL	25	3	63*	6 (NW)	264/13.3
36	NOT NAMED	1934	AUG	28	5	67	85 (E)	180/ 3.0
37	NOT NAMED	1936	JUN	27	3	70	0 (W)	319/ 8.0
38	NOT NAMED	1936	AUG	11	7	35	165 (ESE)	211/ 4.9
39	NOT NAMED	1936	SEP	13	14	30	69 (SW)	310/ 7.6
40	NOT NAMED	1938	OCT	17	5	31	91 (NNE)	287/17.3
41	NOT NAMED	1940	SEP	23	6	40	96 (E)	002/ 8.1
42	NOT NAMED	1941	SEP	16	1	15	114 (NNW)	236/ 6.9
43	NOT NAMED	1941	SEP	23	2	102	93 (E)	348/ 6.4
44	NOT NAMED	1942	AUG	21	1	63*	162 (NE)	319/ 5.3
45	NOT NAMED	1942	AUG	30	2	95	76 (NNE)	309/13.8
46	NOT NAMED	1943	JUL	28	1	50*	154 (NNE)	303/ 5.3
47	NOT NAMED	1943	SEP	17	6	85	95 (ESE)	208/ 5.0
48	NOT NAMED	1944	AUG	22	5	38	175 (SSW)	296/ 7.0
49	NOT NAMED	1944	SEP	9	6	45	178 (ESE)	022/12.8
50	NOT NAMED	1945	JUL	21	2	32	39 (SSE)	241/10.2
51	NOT NAMED	1945	AUG	27	5	110	31 (ESE)	033/ 5.8
52	NOT NAMED	1947	AUG	2	1	40	121 (SSW)	294/ 9.0
53	NOT NAMED	1947	AUG	25	3	60*	141 (NNE)	305/ 5.3
54	NOT NAMED	1949	SEP	22	8	50	126 (ESE)	032/10.3
55	NOT NAMED	1949	OCT	4	10	111	86 (E)	003/15.2

NOTES:
Datetimes are in UTC, winds are in knots, distances are in nautical miles. Parenthetical expression in column 8 gives bearing of storm from site at closest point of approach to site (CPA). Maximum winds are at time of CPA and did not necessarily occur at site. Asterisk (if any) after maximum wind indicates that storm was classified as a hurricane (at least 64 kts) somewhere within 180 nautical mile radius of site but not at CPA. Site location is 27.8°N, 97.2°W.

Table XXVI-1 Continued. Descriptive history of all tropical storms and hurricanes passing within 180 nmi of Ingleside during the period 1886-1992.

1 STORM INDEX NUMBER	2 STORM NAME	3 YEAR	4 MONTH	5 DAY	6 STORM NUMBER FOR YEAR	7 MAXIMUM WIND AT STORM CENTER	8 CPA (CLOSEST POINT OF APPROACH)	9 DDD/SS.S DDD=HEADING SS.S=FORWARD SPEED AT CPA
56	HOW	1950	OCT	3	8	44	150 (SSE)	236/10.6
57	ALICE	1954	JUN	25	1	43*	11[illegible] (SW)	324/13.6
58	ALMA	1958	JUN	15	1	30	117 (SW)	322/14.6
59	ELLA	1958	SEP	6	5	45	3 (W)	291/17.9
60	DEBRA	1959	JUL	24	5	61*	99 (ENE)	345/ 4.9
61	NOT NAMED	1960	JUN	24	1	33	11 (WNW)	353/11.2
62	CARLA	1961	SEP	11	3	120	43 (NE)	329/ 7.0
63	CINDY	1963	SEP	19	4	25*	34 (NW)	226/ 8.6
64	ABBY	1964	AUG	8	3	25	66 (N)	282/ 6.2
65	BEULAH	1967	SEP	21	2	69	56 (WSW)	332/ 4.9
66	CANDY	1968	JUN	23	3	58	12 (NNE)	344/19.7
67	CELIA	1970	AUG	3	3	110	8 (E)	296/14.6
68	FELICE	1970	SEP	16	7	38	153 (NNE)	300/11.0
69	EDITH	1971	SEP	15	6	68	97 (ESE)	033/13.1
70	FERN	1971	SEP	11	7	55*	2 (E)	230/ 4.6
71	DELIA	1973	SEP	5	5	46	63 (ENE)	154/ 6.5
72	CAROLINE	1975	SEP	1	3	30	173 (SSW)	292/ 3.8
73	AMELIA	1978	JUL	31	2	38	44 (WSW)	336/ 8.8
74	DEBRA	1978	AUG	28	5	29	153 (E)	005/10.0
75	ELENA	1979	SEP	1	5	35	81 (ENE)	344/ 6.9
76	ALLEN	1980	AUG	10	1	85	82 (SW)	307/10.0
77	DANIELLE	1980	SEP	6	4	28	75 (N)	261/ 7.1
78	JEANNE	1980	NOV	14	10	50	161 (SE)	056/ 2.9
79	CHRIS	1982	SEP	10	4	37	162 (E)	008/ 6.1
80	ALICIA	1983	AUG	18	1	97	131 (ENE)	343/ 5.3
81	BARRY	1983	AUG	28	2	67	142 (S)	263/10.0
82	NOT NAMED	1987	AUG	10	1	40	153 (ENE)	347/11.3
83	ALLISON	1989	JUN	25	1	30	72 (ESE)	023/ 2.2
84	CHANTAL	1989	AUG	1	3	55*	178 (NE)	310/10.4
85	JERRY	1989	OCT	15	10	70	132 (ENE)	34[illegible]/10.8

NOTES:
Datetimes are in UTC, winds are in knots, distances are in nautical miles. Parenthetical expression in column 8 gives bearing of storm from site at closest point of approach to site (CPA). Maximum winds are at time of CPA and did not necessarily occur at site. Asterisk (if any) after maximum wind indicates that storm was classified as a hurricane (at least 64 kts) somewhere within 180 nautical mile radius of site but not at CPA. Site location is 27.8°N, 97.2°W.

wind speeds marked by an asterisk (*) in column 7 are those observed at CPA and may not represent the tropical cyclone's strongest wind while within 180 nm of Ingleside. An example of this is witn Hurricane Cindy, storm index number 63. The maximum wind at storm center at CPA is listed as 25 kt, but at CPA the storm was northwest of Ingleside, and had obviously weakened over land before it reached its CPA.

The gulf coast near Ingleside is located on the northwest shore of the Gulf of Mexico and is oriented more-or-less perpendicular to normal cyclone tracks across the Gulf of Mexico. An examination of the tracks of hurricanes which passed within 180 nmi of Ingleside during the period 1886-1992 shows that many of the storms maintained a constant west-northwesterly heading as they crossed the Gulf of Mexico to the Texas coast. But others did vary from a constant track and tended to begin a more northerly track (i.e., started recurvature) in the coastal waters near Ingleside. The region's position between 25 and 30 degrees north latitude is within the normal locus of tropical cyclone recurvature which oscillates between latitudes 25°N and 35°N during the tropical cyclone season. This factor is significant since it is characteristic of tropical cyclones to slow and intensify during the recurvature stage. During this phase of the tropical cyclone life cycle, it is difficult to predict with great accuracy the rate of recurvature, the storm speed of movement subsequent to recurvature, and consequently, the storm's precise future position.

The hurricane season along the Gulf Coast is late May through early November. During the 107-year period from 1886 through 1992 there were 85 tropical storms and hurricanes that met the 180 nmi threat criterion for Ingleside, an average of about 0.8 per year. Figure XXVI-4 shows the monthly distribution of the 85 storms. August and September are the months of greatest tropical cyclone threat.

Figure XXVI-5 depicts the yearly distribution of tropical storms and hurricanes passing within 180 nmi of Ingleside. Fifty-one years out of the 107-year history have had no occurrences, including 8 out of the last 13 years of the record. As can be seen in the figure, it is not uncommon to have 2 or 3 years pass without having a tropical storm or hurricane pass within 180 nmi of Ingleside.

Table XXVI-2 shows the monthly frequency and motion history of the 85 tropical storms and hurricanes which passed within 180 nmi of Ingleside during the period 1886-1992. The average movement for the storms at their closest point of approach (CPA) is 319° at 10 kts. Approximately 2 of every 5 tropical cyclones that approach within 180 nmi of Ingleside are of hurricane intensity.

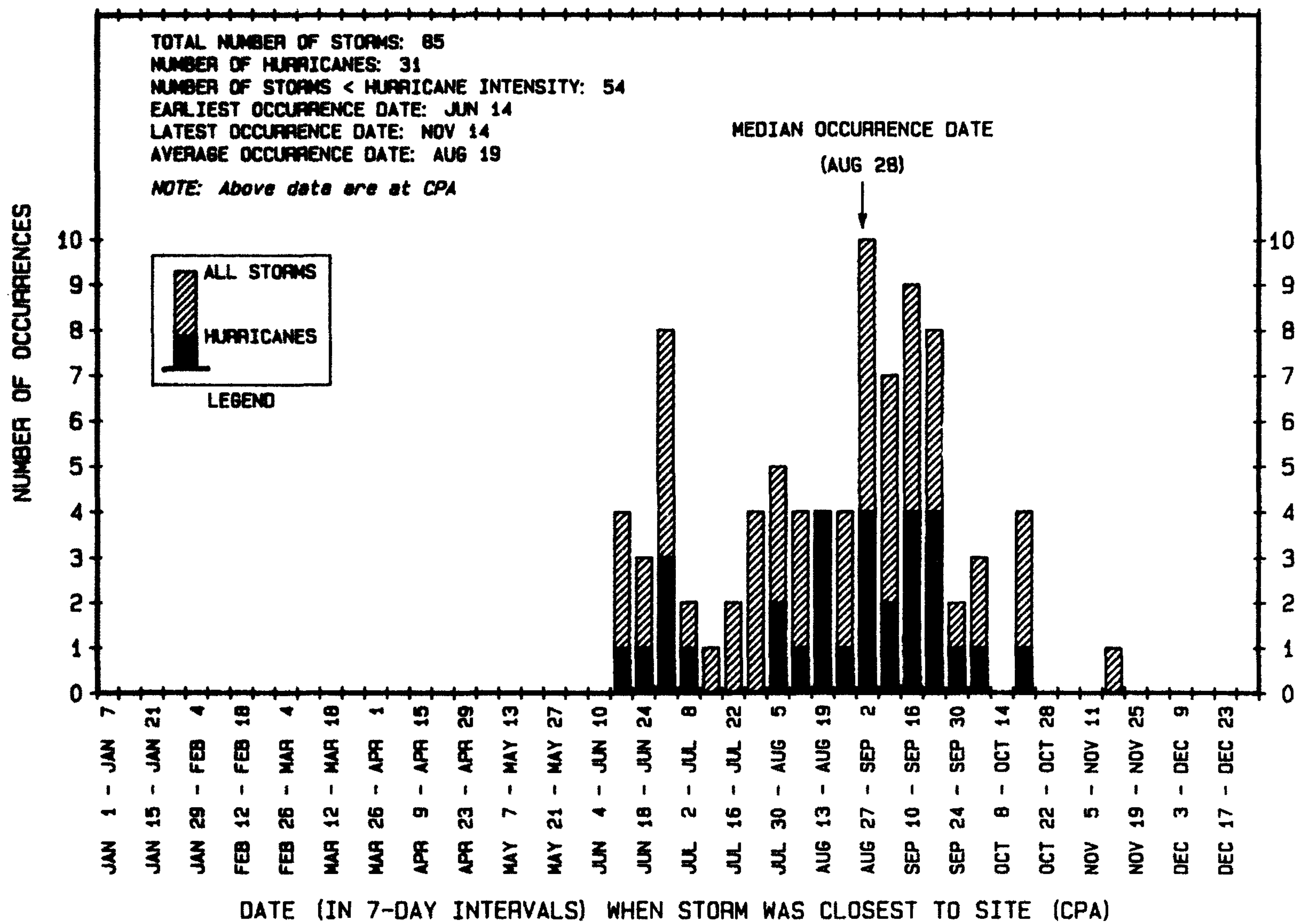

Figure XXVI-4. Monthly distribution of all tropical storms and hurricanes passing within 180 nmi of Ingleside during the 107 year period 1886-1992.

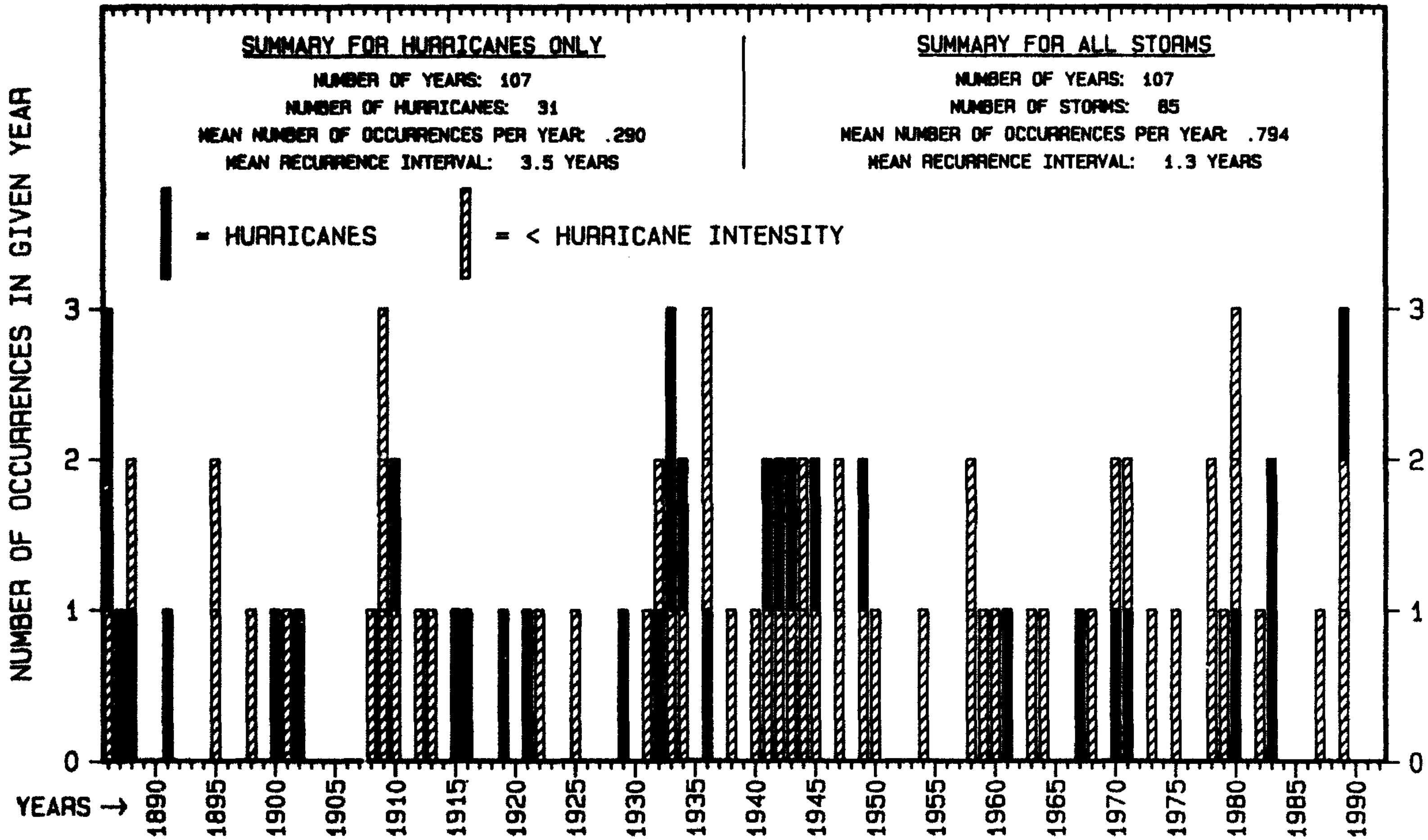

Figure XXVI-5. Chronology of all tropical storms and hurricanes passing within 180 nmi of Ingleside during the 107 year period 1886-1992. Storm intensity is determined at time of closest point of approach (CPA) to Ingleside.

Table XXVI-2. Frequency and motion of tropical storms and hurricanes passing within 180 nmi of Ingleside over the 107 year period 1886-1992.

Total number of storms passing within 180 n mi	0	0	0	0	0	15	10	25	27	7	1	0	85
Number of storms having at least hurricane intensity at CPA	0	0	0	0	0	5	1	12	12	2	0	0	32
Number of storms less than hurricane intensity at CPA	0	0	0	0	0	10	9	13	15	5	1	0	53
Average heading (degs) towards which storms were moving at CPA	---	---	---	---	---	331	315	303	320	339	*	---	319
Average storm speed (knots) at CPA	---	---	---	---	---	12	10	9	8	14	*	---	10
Month when storm was at CPA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR

** indicates insufficient storms for average direction and speed computations.*

Figure XXVI-6 presents a graphical depiction of the number of tropical cyclones versus CPA. The storm classification is based on the maximum wind near the storm center while that center was within 180 nmi of Ingleside, and not necessarily at CPA. The sloping lines represent a mathematical fit to data points.

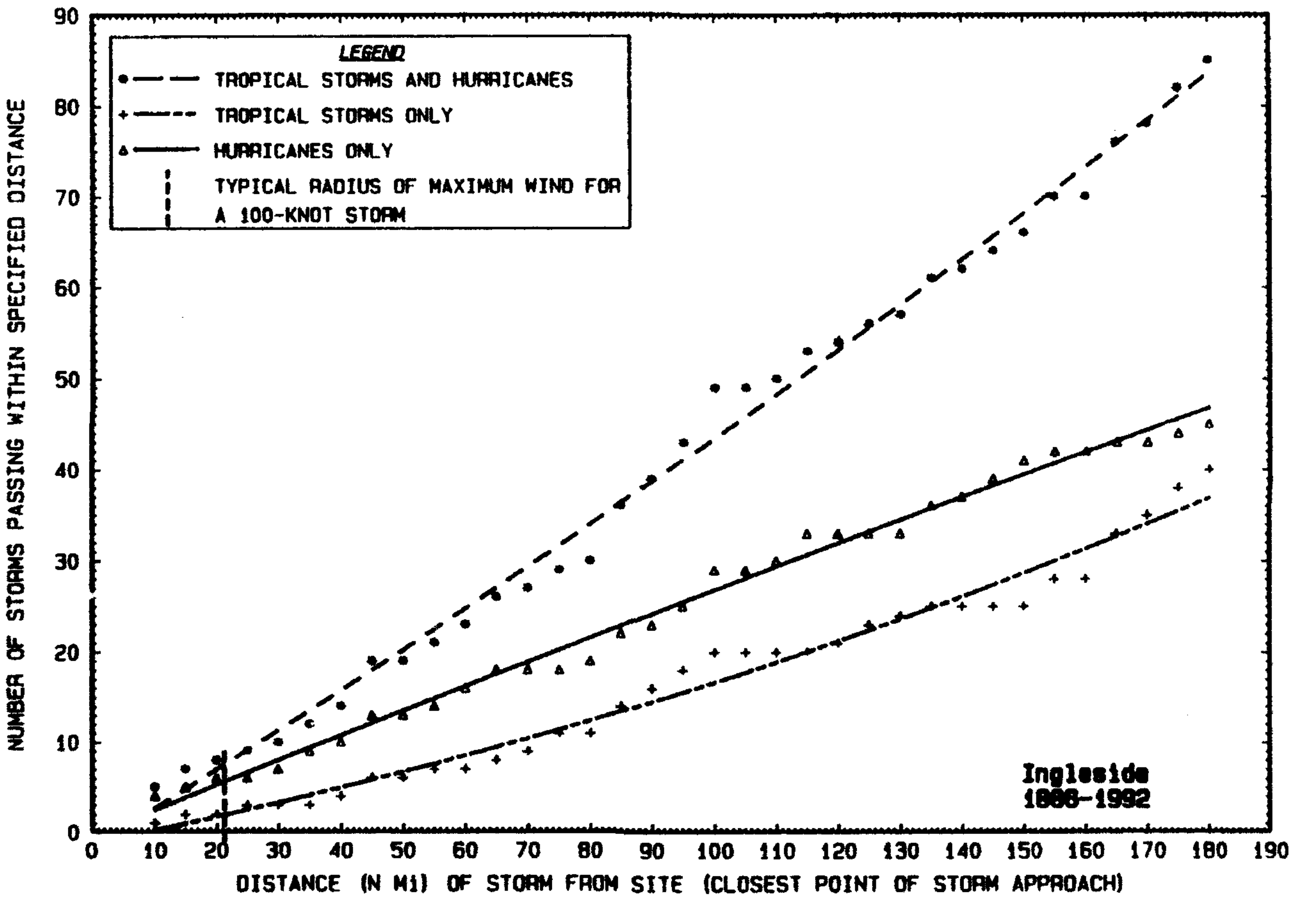

Figure XXVI-6. Number of tropical cyclones passing at various distances from Ingleside over the 107-year period of record. Tropical storm or hurricane classification is based on maximum wind near storm center while that center was within 180 nmi of the site, and not necessarily at CPA. Sloping lines represent mathematical fit to data points. Average radius of maximum wind for 34, 100, and 140 kt storms at Ingleside are 22.8, 21,2, and 18.3 respectively.

Figure XXVI-7 displays the storms as a function of the compass octant from which they approached Ingleside. It is evident that the major threat from tropical cyclones is from the east clockwise through south.

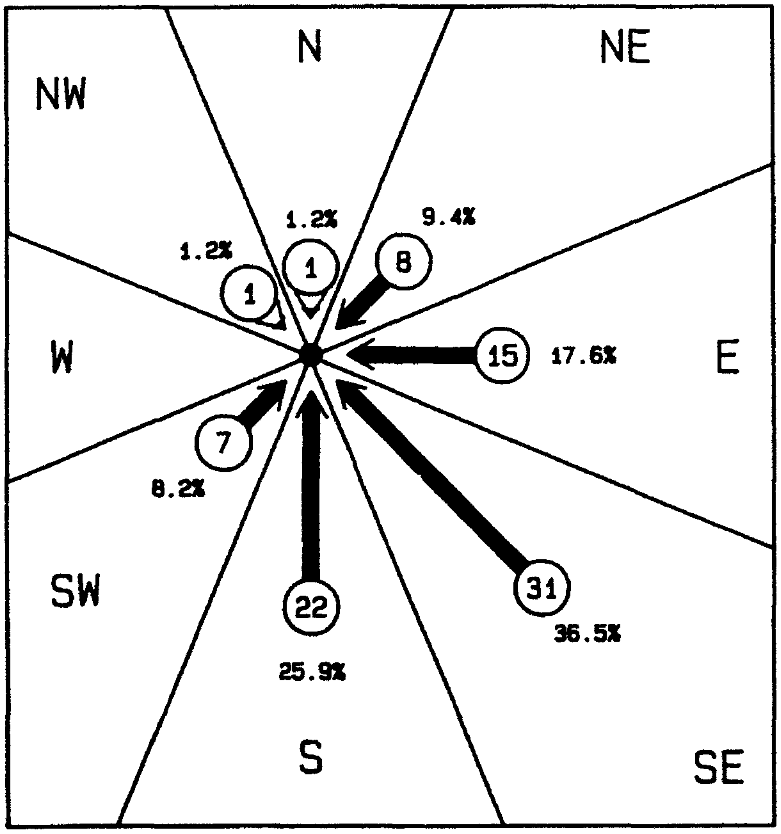

Figure XXVI-7. Directions of approach for 85 tropical cyclones passing within 180 nmi of Ingleside during the 107 year period of record. Length of directional arrow is proportional to the number of storms given in the circles of each octant. Approach directions are determined at CPA.

A comparison of Figures XXVI-8 through XXVI-10 shows some distinct differences in threat axis according to time of year. The least active period, October through June, has a maximum threat axis extending southeastward from Ingleside through the Gulf of Campeche, across the Yucatan Peninsula and into the western Caribbean Sea. The months of July and August have a narrowly defined threat axis extending east-southeast-ward from Ingleside through the Yucatan Channel, thence across the Caribbean Sea just south of Cuba, Hispaniola and Puerto Rico and across the Leeward and Windward Islands into the south Atlantic Ocean. The threat Axis for September is similar to that of July/August, but not as narrowly defined.

3.3 ENVIRONMENTAL EFFECTS

3.3.1 WIND AND TOPOGRAPHY

The relatively low-lying topography surrounding Naval Station Ingleside affords little protection; the station is exposed to the full effects of tropical cyclone winds. History has shown that the region is susceptible to strong winds and associated weather phenomena. Table XXVI-3 lists wind and weather data recorded during specific storm occurrences at Ingleside. Table XXVI-4, included in Section 3.3.2 below, lists additional storm surge data from other unidentified locations on the Texas coast.

3.3.2 STORM SURGE AND TIDES

Storm surge may be visualized as a raised dome of water, moving with the storm, and centered a few miles to the right of its path. The dome height is related to local pressure (i.e., a barometric effect dependent on the intensity of the storm) and to local winds. Other significant contributing factors are storm speed, direction of approach, bottom topography, and coincidence with astronomical tide.

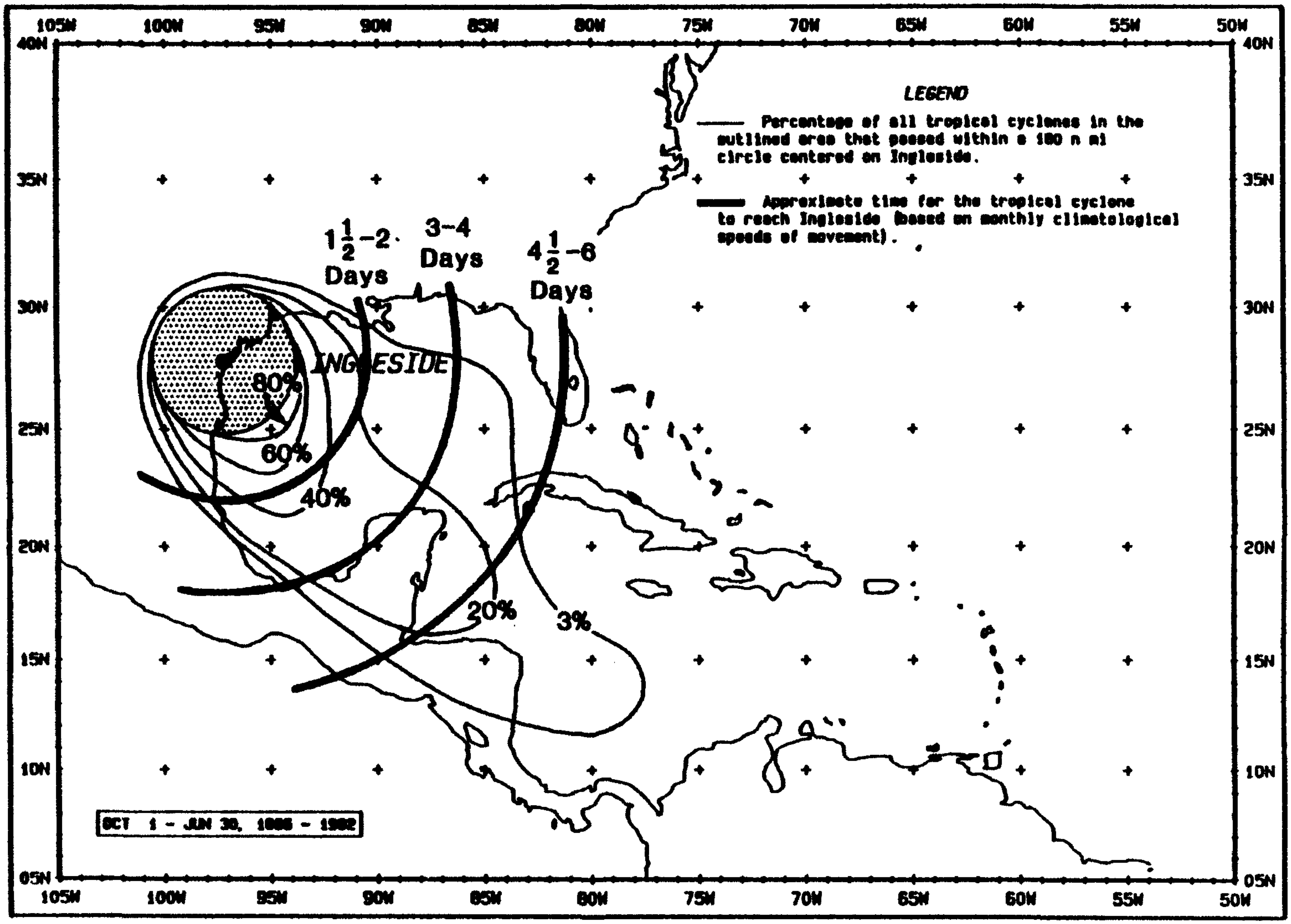

Figure XXVI-8. Probability that a tropical storm or hurricane will pass within 180 nmi of Ingleside (circle), and approximate time to closest point of approach, during the period October through June (based on data from 1886-1992).

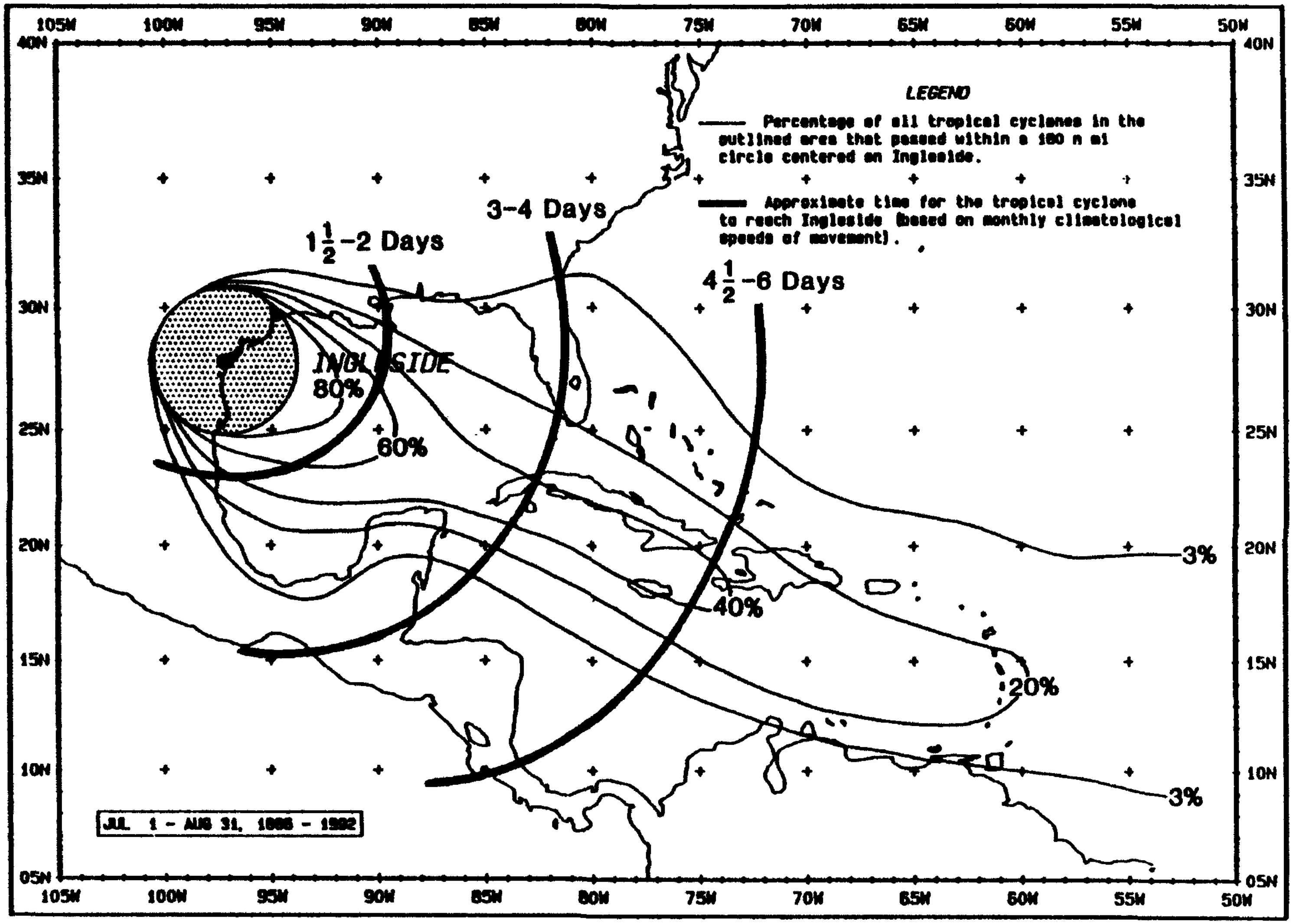

Figure XXVI-9. Probability that a tropical storm or hurricane will pass within 180 nmi of Ingleside (circle), and approximate time to closest point of approach, during the period July and August (based on data from 1886-1992).

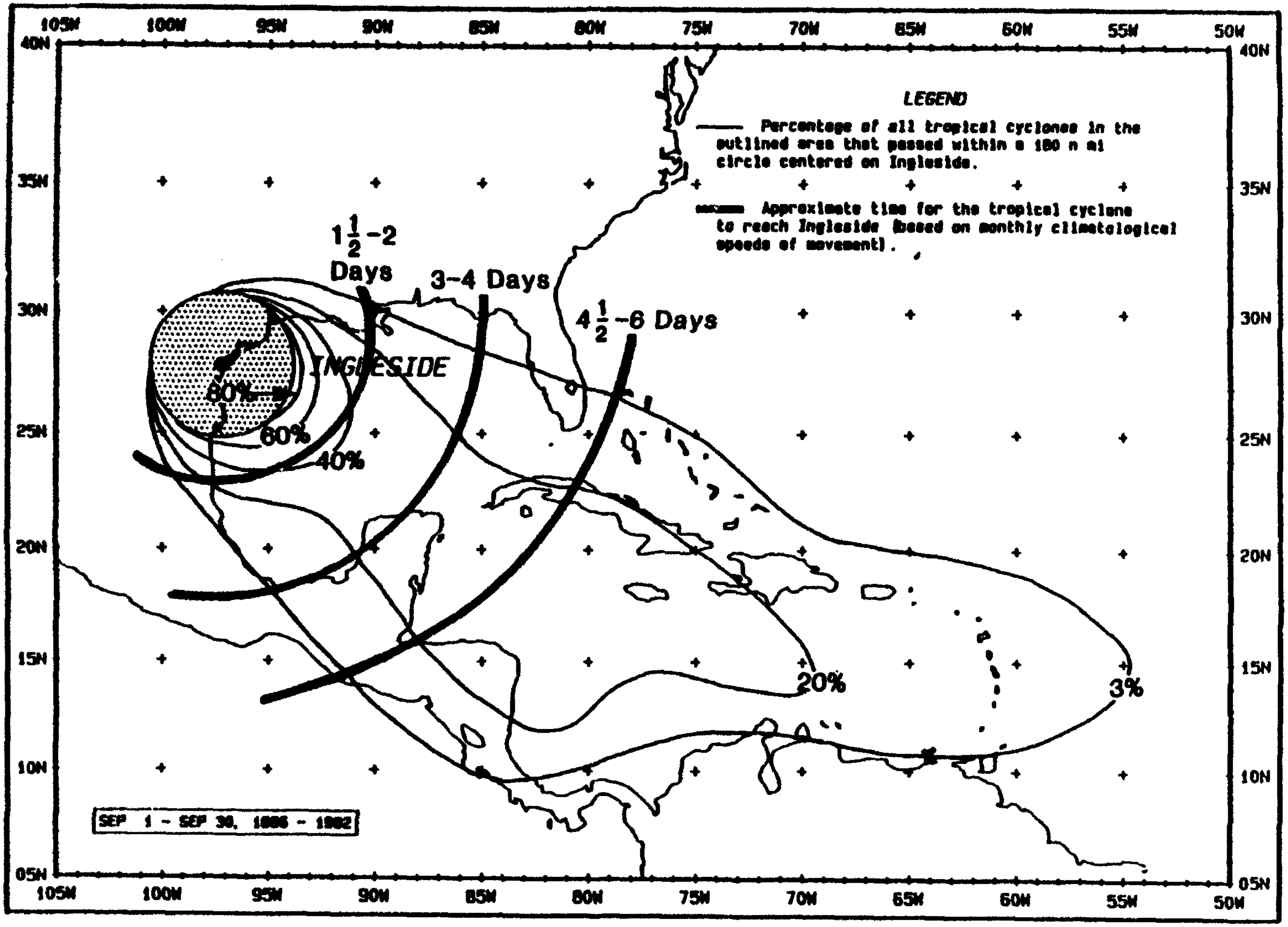

Figure XXVI-10. Probability that a tropical storm or hurricane will pass within 180 nmi of Ingleside (circle), and approximate time to closest point of approach, during September (based on data from 1886-1992).

Table XXVI-3. Center data and related weather associated with selected tropical cyclones which passed within 180 nmi of Ingleside during the period 1949 through 1980.

HURRICANE DATA				RELATED WEATHER IN INGLESIDE AREA			
DATE (NAME)	SOA (KT)	DIR/CPA (N.MI)	CNTR (KT)	MAX WIND AND GUST (KT)	SURGE HT (FT)	MAX PRECIP 24/6 HR (IN.)	(*)
10/30/50	10	S/163	54	NE 28+34		NO RAIN	
6/27/57 AUDREY	14	E/175	72	ENE 22+29			A
6/15/58	13	W/113	41	SE 24+28			B
9/15/58	16	SW/45	41	N 32+44		2.19	C
9/11/61 CARLA	5	E/57	103	N 50+71		8.0-10.0 ESTIMATED	
9/20/67 BEULAH	8	W/51	74	SE 54+75		6.38/3.48	D
8/3/70 CELIA	14	NE/33	100	WSW 95+140	10	6.30	E
9/10/71 FERN	12	E/162	45	NW 44+61		3.74/1.74	
9/5/73	7	E/66	45	NNW 27+41			D
7/31/78	9	SW/51	40	S 33+50		3.77	
8/10/80 ALLEN	7	SW/85	85	E 45+80		13.27 IN 48 HRS.	

* COMMENTS

A. Tanker, Tug, 2 barges aground Port Aransas. Strong cross current at channel mouth.
B. Offshore seas 10 to 15 feet.
C. Tornadoes in area.
D. Funnel clouds.
E. Wind, Gust and precipitation are estimated. Complete power failure. Meteorological equipment destroyed by wind.

Tornadoes are a significant destructive element to consider for tropical cyclones and their effect on the Texas coast. Hurricane Beulah, a September 1967 storm, set a national record for the number of tornadoes, with separate sources variously reporting either 115 or 155 as the total number, with 67 occurring in one day.

The worst combination of circumstances (Harris, 1963, and Pore and Barrientos, 1976) would include:

(1) An intense storm approaching perpendicular to the coast with the harbor within 30 nmi to the right of the storm's track.

(2) Broad, shallow, slowly shoaling bathymetry.

(3) Coincidence with high astronomical tide.

The continental shelf adjacent to Ingleside is relatively narrow when compared with most other locations in the Gulf of Mexico. According to Jarvinen, et al., (1985), the 60-ft depth is 6 to 7 miles from shore. The bottom is primarily sand and no reefs exist near the shore. Therefore, the beach is susceptible to the erosive force of breaking waves generated by a hurricane. But it is shoreline and near shoreline developments that are at risk from storm surge. Naval Station Ingleside is constructed on land above anticipated storm surge levels (Perryman, 1991), and much of the area is developed on the high bluffs that surround Corpus Christi Bay. The city of Corpus Christi itself is about 38 ft above sea level. The average depths in Corpus Christi Bay range from 2 to 13 ft, with the greater depths located near the center of the bay. Corpus Christi Channel, which leads from Aransas Pass to Naval Station Ingleside and westward to Corpus Christi, has an average depth of 43 ft, and an average width of 900 ft. It can transport a significant amount of water into or out of Corpus Christi Bay when a strong tropical cyclone affects the region.

Another factor in how storm surges affect the area is the extensive barrier island configuration along the Texas coast which contains massive and broad sand dunes. The island buffering Ingleside and the general Corpus Christi area from the Gulf of Mexico is called Mustang Island. The sand dunes on this island range from 3 to 25 ft with the average height being 12 to 13 ft, and often extend inland several hundred feet.

The following excerpt from <u>A Storm Surge Atlas for Corpus Christi, Texas</u> is relevant.

"The importance of the sand dunes being broad was demonstrated in hurricane Allen of 1980. The eye of this hurricane made landfall just north of Port Isabel, Texas near the Texas/Mexico border. Thus, the barrier islands northward were subject to storm surge and pounding waves. On Mustang Island and Padre Island approximately 100 feet of sand dunes were eroded. Before Allen 50 feet of beach were present between the sand dunes and shoreline. Afterwards 150 ft of beach existed. However, the sand dunes looked just as formidable after Allen as before.

During Allen the lower portion of Padre Island was overtopped in many locations because of the numerous gaps. The erosion was so extensive in many locations that channels were cut across the island. Since Allen, the channels have filled near the Gulf side of the barrier islands. On the upper portion of Padre Island and on Mustang Island the sand dunes have been rebuilding toward the Gulf of Mexico.

Under normal tidal conditions water is exchanged between the Gulf of Mexico and Corpus Christi Bay by means of a channel which enters the Gulf of Mexico at Port Aransas. The "Achilles heel" of the Corpus Christi basin exists just north of Port Aransas. For approximately 4 miles sand dunes are non-existent and the barrier island averages 3 feet. This 4 mile strip is easily overtopped during any hurricane and the water pouring over this strip can add a significant amount of water to Corpus Christi Bay."

History has shown that the Texas coast is susceptible to storm surge. Several hurricanes have caused considerable damage during this century, some of which are described in Table XXVI-4.

Table XXVI-4. Historical record of hurricane tide elevations at non-specific locations along the Texas coast. Exact elevations at Ingleside are not recorded. Compiled from unidentified documents.

DATE	STORM NAME	HEIGHT ABOVE MEAN SEA LEVEL
SEPTEMBER 8, 1900	UNNAMED	15-20 FT
AUGUST 17, 1915	UNNAMED	15-20 FT
AUGUST 13, 1932	UNNAMED	10-15 FT
OCTOBER 3, 1949	UNNAMED	10-15 FT
JUNE 27, 1957	AUDREY	12+ FT
SEPTEMBER 11, 1961	CARLA	15-22 FT
AUGUST 9, 1980	ALLEN	8-12 FT

Research in storm surge prediction techniques has led to the development of an advanced storm surge forecasting tool. Developed by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service, it is known by its acronym "SLOSH", which stands for Sea, Lake, and Overland Surges from Hurricanes (Jelesnianski and Chen, 1979).

The SLOSH model calculates storm surge values for five storm intensities, each corresponding to a category on the "Saffir/Simpson Scale". This scale, shown in Table XXVI-5, was developed by Herbert Saffir and Dr. Robert H. Simpson.

Table XXVI-5. Saffir/Simpson scale.

	CENTRAL PRESSURE		WIND		
SCALE NO.	MB	INCHES	MPH	KNOTS	DAMAGE
1	>980	>28.94	74-95	64-83	Minimal
2	965-979	28.50-28.91	96-110	84-95	Moderate
3	945-964	27.91-28.47	111-130	96-113	Extensive
4	920-944	27.17-27.88	131-155	114-135	Extreme
5	<920	<27.17	155+	135+	Catastrophic

The results of the SLOSH model for Ingleside are provided in the NOAA technical report, A Storm Surge Atlas for Corpus Christi, Texas. The report contains computer-gridded charts with storm surge heights computed for several locations and situations, including hurricane categories 1 through 5 approaching the Ingleside area on different tracks, at different speeds, and at varying distances and directions from Corpus Christi. Tables XXVI-6A, XXVI-6B, and XXVI-6C list the anticipated surge heights for the Ingleside area during the identified situations.

Table XXVI-6A. Storm surge heights for the Naval Station Ingleside area for northwesterly moving storms. Passing side and distances of storm are in relation to Port Aransas. Heights are in relation to mean sea level and are listed in feet. Heights have been approximated to the nearest 0.5 ft from chart contours contained in A Storm Surge Atlas for Corpus Christi, Texas.

DIR OF STORM MVMT	STORM SPEED (KT)	PASSING SIDE OF STORM*	DISTANCE FROM PT ARANSAS	SAFFIR/SIMPSON CATEGORY				
				1	2	3	4	5
NW	10	LEFT	70	2.5	3.0	3.5	3.5	3.0
NW	10	LEFT	60	2.5	3.0	4.0	4.0	3.0
NW	10	LEFT	50	3.0	3.5	4.0	5.0	3.0
NW	10	LEFT	40	3.0	4.0	5.0	7.5	3.5
NW	10	LEFT	30	3.5	4.0	6.5	9.5	4.5
NW	10	LEFT	20	3.5	4.5	7.0	10.5	5.5
NW	10	LEFT	10	3.5	4.5	7.0	9.5	7.5
NW	10	OVER	0	3.0	3.5	4.5	6.0	6.0
NW	10	RIGHT	10	2.5	3.0	3.5	4.0	4.0
NW	10	RIGHT	20	2.5	2.5	3.0	3.0	3.0
NW	10	RIGHT	30	2.0	2.0	2.5	2.5	2.0
NW	5	LEFT	30	4.0	4.5	7.5	10.0	5.5
NW	5	LEFT	20	4.0	4.5	8.0	10.5	7.5
NW	5	LEFT	10	4.0	4.5	7.0	9.0	8.0
NW	20	LEFT	30	3.0	4.0	5.5	8.5	4.0
NW	20	LEFT	20	3.0	4.5	5.5	9.5	4.5
NW	20	LEFT	10	3.0	4.0	5.5	8.5	6.0

* Passing side is determined by looking forward along the hurricane track.

Table XXVI-6B. Storm surge heights for the Naval Station Ingleside area for westerly moving storms. Passing side and distances of storm are in relation to Port Aransas. Heights are in relation to mean sea level and are listed in feet. Heights have been approximated to the nearest 0.5 ft from chart contours contained in A Storm Surge Atlas for Corpus Christi, Texas.

DIR OF STORM MVMT	STORM SPEED (KT)	PASSING SIDE OF STORM*	DISTANCE FROM PT ARANSAS	SAFFIR/SIMPSON CATEGORY				
				1	2	3	4	5
W	10	LEFT	70	3.0	3.0	4.0	4.5	3.0
W	10	LEFT	60	3.0	3.5	4.0	5.5	3.0
W	10	LEFT	50	3.0	4.0	5.0	7.5	3.5
W	10	LEFT	40	3.5	4.0	6.5	10.0	4.0
W	10	LEFT	30	3.5	4.5	7.5	11.5	5.0
W	10	LEFT	20	3.5	4.5	7.5	11.0	6.0
W	10	LEFT	10	3.5	4.0	6.0	9.5	7.0
W	10	OVER	0	3.0	3.0	4.0	5.0	6.0
W	10	RIGHT	10	2.5	2.5	3.0	3.0	4.0
W	10	RIGHT	20	2.0	2.0	2.0	3.0	3.0
W	10	RIGHT	30	2.0	2.0	2.0	2.0	2.0
W	5	LEFT	30	4.0	4.5	7.0	10.5	5.0
W	5	LEFT	20	3.5	4.0	7.0	10.5	7.0
W	5	LEFT	10	3.5	3.5	5.5	8.0	6.5
W	20	LEFT	30	3.0	4.0	6.0	9.0	4.0
W	20	LEFT	20	3.0	4.0	5.5	9.0	5.0
W	20	LEFT	10	3.0	3.5	4.5	6.5	4.5

* Passing side is determined by looking forward along the hurricane track.

Table XXVI-6C. Storm surge heights for the Naval Station Ingleside area for north-northwesterly and southwesterly moving storms. Passing side and distances of storm are in relation to Port Aransas. Heights are in relation to mean sea level and are listed in feet. Heights have been approximated to the nearest 0.5 ft from chart contours contained in A Storm Surge Atlas for Corpus Christi, Texas.

DIR OF STORM MVMT	STORM SPEED (KT)	PASSING SIDE OF STORM*	DISTANCE FROM PT ARANSAS	SAFFIR/SIMPSON CATEGORY		
				1	2	3
NNW	10	LEFT	150	2.5	3.0	4.0
NNW	10	LEFT	50	3.5	3.5	5.0
NNW	10	LEFT	20	4.0	4.0	6.5
NNW	10	OVER	0	3.0	4.0	5.0
NNW	10	RIGHT	20	2.5	3.0	3.0
NNW	5	LEFT	150	3.0	3.5	5.0
NNW	5	LEFT	50	3.5	4.0	5.5
NNW	5	LEFT	20	4.0	4.5	7.0
NNW	5	OVER	0	3.5	3.5	5.5
NNW	5	RIGHT	20	2.5	3.0	3.0
NNW	20	LEFT	150	2.5	2.5	3.0
NNW	20	LEFT	50	3.0	3.5	4.5
NNW	20	LEFT	20	3.0	4.0	6.0
NNW	20	OVER	0	3.0	3.5	5.0
NNW	20	RIGHT	20	2.5	3.0	3.0
SW	10	LEFT	40	3.0	3.5	N/A
SW	10	OVER	0	2.0	2.0	N/A

* Passing side is determined by looking forward along the hurricane track.

The highest forecast storm surge water level for Ingleside is approximately 11.5 ft above mean sea level, which is attained with a 10 mph westerly moving, category 4 hurricane passing 30 miles south of Ingleside. Other hurricane scenarios produce 10 to 11 ft water levels. In addition to increases in water levels, SLOSH also computes the lowering of water levels when water is forced out of a basin due to off-shore winds. The lowest water level at Ingleside, 8-9 ft below mean sea level (not shown in the tables), is forecast to occur during a 20 mph westerly moving, category 5 hurricane passing 10 miles south of Ingleside. Both a 10 mph northwesterly moving, category 5 hurricane passing 10 mi south of Ingleside, and a 10 mph westerly moving, category 5 hurricane passing 10 mi south of Ingleside are forecast to depress the water levels about 7 ft below mean sea level. In each of the low water cases, the period of lowest water is extremely short and followed by a significant rise in the water level above mean sea level. For example, in the extreme low water case referred to above, 8-9 ft below mean sea level, the water level is expected to quickly rise to about 7 ft above mean sea level, resulting in a net water level change of about 15 ft in about 1 hour. Such a rapid change in water level could be the potential cause of significant storm surge damage in the Corpus Christi Bay area. Readers are referred to NOAA Technical Memorandum NWS NHC 27 for explanations and details of SLOSH forecasts for Ingleside.

4. THE DECISION TO EVADE OR REMAIN IN PORT

At the time of the port visit (Perryman, 1991), the base was not yet in full operation, but was already hosting ship visits. A comprehensive Hurricane Bill, Naval Station Ingleside Instruction 3730.1, had been drafted addressing essential emergency measures to be taken in the event of a hurricane threat. Material from the Hurricane Bill was used in developing the following decision aids.

4.1 THREAT ASSESSMENT

The tropical cyclone threat analysis presented in Section 3 of this evaluation indicates that Naval Station Ingleside is at considerable risk to hurricane damage, primarily from high winds since the Naval Station is constructed above anticipated storm surge heights. Little protection is provided by surrounding terrain. Early assessment of each potential threat is essential, and should be related to the setting of hurricane conditions of readiness by military and civil authorities, based on current advisories and forecasts issued by the Navy and National Weather Service, as well as climatology as presented herein.

Individual storm intensity and speed of movement will affect the potential for damage which can be expected from any given storm. As a general rule, any intense tropical storm or hurricane approaching from the Gulf of Mexico such that Corpus Christi Bay is located in the dangerous right front quadrant of the storm can result in severe wind and storm surge conditions.

4.2 EVASION AT SEA

NAVSTAINGLESIDEINST 3730.1 states that sortie is NOT the recommended course of action for all ships when Ingleside is directly threatened with destructive force winds or an inundating severe storm surge from a tropical cyclone.

The rationale given for the recommendation not to sortie is based on several factors, including the geographical location and coastal orientation of the Gulf of Mexico and the limited evasion speed of Mine Warfare ships homeported at Ingleside. If sortie is chosen, it should be initiated by SOPA as soon as it can be established that a particular tropical cyclone poses a threat to Ingleside. Ideally, no later than about 48 hours prior to the onset of gale force ($\geq$34 kt) winds, approximately coincident with the setting of Hurricane Condition Three. Although at this time the storm center may be more than 500 nmi distant, it should be remembered that the 48-hour forecast error is greater than 200 nmi. The storm center could be significantly closer to or farther from Ingleside than the forecast indicates, or to the right or left of the forecast track.

Early assessment of each potential threat is essential. Assessment should be related to the setting of hurricane conditions of readiness by military and civil authorities, and consideration of current advisories and forecasts issued by the Navy and National Weather Service, as well as climatology. The need for early sortie from Ingleside is a result of the coastline orientation, the nature of the harbor makeup, and the distance to deep water. Also, the concave shape of the coastline restricts running room in all directions. Although NAVSTAINGLESIDEINST 3730.1 states "If sortie has not commenced (SOPA issues order) within 24 hours of the expected arrival of hurricane force winds, a firm commitment to remain in port should be made.", units considering sortie would be well advised to make the sortie decision well before that time.

Once sea room is attained, the tactics employed will depend on the location of the threatening tropical cyclone, its speed of advance, and its direction of movement.

Up-to-date information is essential if sound decisions are to be made. Tropical cyclone location and intensity information based on today's satellite technology is accurate and timely. Forecasts and warnings are issued at 6-hourly intervals and updated as necessary to reflect important changes in position, intensity, and movement. Ship masters with access to these advisories/warnings are in the best possible position to modify evasion routes and tactics to successfully evade the storm.

Regardless of the evasion route planned, if evasion at sea is chosen, an early decision is critical. Timing of the decision to evade is affected by:

(1) The forward speed of the tropical cyclone.

(2) The radius of hazardous winds and seas that can impact on a vessel's ability to reach open water and then maneuver to evade.

(3) The elapsed time to make preparations to get underway.
(4) The elapsed time to reach open water.
(5) The speed rating of the vessel in open water.

For example:

Even the most modern ships in the Navy inventory require a few hours to get underway. If 6 hours are required to make preparations for sortie after the decision to evade at sea is made, and another 2 hours are required to transit to open sea, a hurricane approaching at 10 kts will be 80 nmi closer by the time open water is reached. When the radius of strong winds likely to hamper operations, about 200 nmi, is added, it gives 280 nmi (or 28 hours) as the absolute minimum hurricane displacement from Ingleside when the decision must be made to evade at sea without running the risk of encountering heavy weather immediately upon departing Aransas Pass. A greater time margin may be applicable, depending on an increased storm speed of advance, if the radius of strong winds is larger, or reduced ship speed capability.

The following guidelines are offered.

(1) Tropical cyclone rapidly approaching from the southeast: This is the worst hurricane approach scenario for ships at Ingleside. The <u>best</u> option available for evading vessels is to take an east-northeasterly heading from Aransas Pass with the aim of having the storm pass south of them. This would be an extremely hazardous course of action if begun too late or if the storm would start to recurve thereby placing the evading ships directly in its path. Ships taking this course can expect to encounter head winds and seas and may have to reduce their speed of advance. The alternative sortie option is attempting to "cross the T" by going south in front of the storm with the aim of getting on the weaker left side of the circulation. This is considered to be even riskier. If the storm should accelerate or change its course to westerly, the evading ships could be placed directly in the path of the storm. Suggested advice is to not attempt a sortie.

(2) Tropical cyclone approaching from the east: Depart early and steam south or south-southeast to gain a position on the weaker south side of the storm, while taking advantage of following northerly winds and seas. While tropical cyclones do not normally move appreciably south of a westerly track in the western Gulf of Mexico, it is possible. An early departure is essential if a safe sortie is to be accomplished. Again, it should be borne in mind the significance of the fact that the 48-hour forecast position average error for tropical cyclones is over 200 nmi, with the result that the storm may be closer to or farther from Ingleside, or right or left from the forecast track at the end of the forecast period than the forecast indicates.

4.3 RETURNING TO PORT

The damage and disarray at a port resulting from a tropical cyclone strike may include navigation hazards such as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Naval Station services may be so damaged as to preclude offering even minimal services for several days following a damaging strike.

4.4 REMAINING IN PORT

Little protection from wind is available at Naval Station Ingleside. If a vessel chooses to remain in port or cannot get underway due to mechanical problems, it should be ballasted down as much as possible, and secured to the dock with sufficient mooring lines, including spring lines, to withstand predicted wind forces, yet allow for water height fluctuations of up to 15 ft as predicted by the SLOSH model.

If the decision is made to remain in port it should be borne in mind that the vessel will be exposed to dangers beyond that of wind and storm surge. Vessels in other portions of Corpus Christi Bay may break loose from their moorings and become floating hazards. Material damage may result from foreign matter being deposited in machines and other equipment. Also, there is a danger that a damaged or sunken vessel could effectively block the narrow ship channels and trap shipping at the pier for some time after a storm has passed.

4.5 ADVICE TO SHALLOW DRAFT VESSELS

Since the Naval Station is constructed above the highest anticipated storm surge levels, small craft should be removed from the water and secured above forecast water levels. There are a number of small channels and canals used by small boats in the Corpus Christi Bay area, but none offer sufficient protection from the effects of the passage of a strong tropical cyclone. Nueces River empties into the west portion of Nueces Bay, and is navigable for shallow-draft boats for about 9 miles to the base of a dam. However, fresh water flooding from heavy rain runoff is a problem throughout the region. Since the river currents would likely become dangerously fast and the water would inundate river-side facilities as it spilled over its banks, the river would not provide a suitable haven for small boats. The same conditions would apply to the other rivers and streams which drain into Corpus Christi Bay.

Using open water anchorages to ride out the passage of a tropical cyclone is extremely hazardous. Virtually no protection is afforded except near lee shores. Wind wave activity can be quite destructive, not to mention the hazards of floating debris resulting from the effects of wind waves, high water, and high winds.

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PORT VISIT INFORMATION

November 1991. NRL Meteorologist Dennis Perryman met with CDR Ventgen and AGCS Percer of Naval Station Ingleside to obtain a portion of the information contained in this report.